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RECLAMATION OF TIDE-LANDS,

AND

ITS RELATION TO NAVIGATION.

BY

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FROM THE COAST SURVEY REPORT FOR 1869.

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ON THE RECLAMATION OF TIDE-LANDS, AND ITS RELATION TO NAVIGATION.

PART I.—GENERAL DISCUSSION OF THE SUBJECT.

Relations of the Coast Survey.—Although, as a general rule, marshes reclaimed from rivers and tide-waters by drainage are the most fertile and enduring of all soils, the cases are exceptional where enterprises in this direction are profitable prior to the period when an augmenting population has exhausted the resources of the uplands. In our own country, lands have been reclaimed from time to time since the earliest settlement; but until recently efforts of this kind have been confined to high marshes bordering upon rivers or sheltered bays, and in most cases for the growth of special crops. The period, however, has arrived when the sea-board of our Northern States has become so densely populated that projects of reclamation are becoming popular, and promise favorable investments for capital. The topographical sheets of our Coast Survey, which reach the public only as printed maps, upon scales so reduced that many of the details and most of the original spirit are lost, furnish us with an amount of information relative to the extent and character of the tide-marshes along our shores scarcely appreciated by those outside of our service. These surveys in the manuscript, as they reach us from the plane-table, furnish not only the measures of reclaimable marshes, but exhibit the configuration of the surrounding country so boldly, and at the same time so minutely, that one can scarcely cast his eyes over one of these sheets without superinducing upon it tempting schemes of conquest. To the engineer every detail of the topography has a practical value, which he cannot afford to overlook in developing a scheme of drainage.

In the reclamation of tide-lands it is all-important, because it is the best economy, to so arrange the dikes, canals, and sluices that the largest possible area shall be included in one comprehensive plan. These enterprises are profitable in the measure that they combine individual interests and assume the proportion of public works. In the same measure also the Coast Survey, I think, should be ready and willing to furnish information, not only through maps and printed reports, but also through its officers in person; the topographer with his sheet before him can be of more value in oral discussions of projects than by writing reports, because he cannot know in advance the means or the wants of the people. He is not at all competent to originate the project, but very well able to assist a community in doing so. In a corps like ours, composed of men selected carefully and trained to scrupulous truthfulness in the study of nature, I should feel no anxiety with regard to the character of the advice that individual officers might give. They feel their reputations involved in the success of the undertakings as well as in the preservation of their entire freedom from private interests.

The relations of encouragement and of assistance, which I have indicated as my notion of a proper policy for the Coast Survey, are not the only or the most important interests which we have in these opening enterprises; we should be watchful of them, because they involve effects upon navigable channels sometimes beneficial, sometimes detrimental. We should favor legislative grants in some cases and oppose them in others. Perhaps there is no navigable stream that can be safely left to the exclusive control of the communities upon its banks. In my studies of foreign works of reclamation, whose histories have been preserved through long periods, I scarcely find the instance where the enclosure of tide-lands in the vicinity of channels is neutral in its effects upon navigation. It seems to me, therefore, that our first thought upon this subject should be from a commercial point of view.

To any one whose memory goes back to the time when railways were unknown, or to any one whose travels have extended beyond the sound of the steam-whistle, I need hardly say that the recent improvements in land transportation have had a tendency to diminish with us the number of small vessels known as "market-men," whose mission it has been to ply between the great seaports and the little coves and inlets of the adjacent coast. In the early settlement of the country it was all-important to the agriculturist to find a location in the vicinity of a navigable water-course, in order that the products of his labor might be within reach of a market; and on the other hand, very shallow streams and really dangerous harbors became, in some cases, the sites of considerable commerce, simply because they afforded the only available avenues to a productive country.

In these modern times a change has come over the spirit of migration and trade, and among its first fruits we find that many of the smaller streams and harbors are falling into comparative disuse. The time is come indeed when the farmer covets the rich soils that lie submerged, and is quite ready to entertain any project of reclamation regardless of its effect upon navigation.

Were the entire value of a water-course always to be measured by its service, as an avenue for "market-men," the conversion of its territory from commercial to agricultural uses would be generally popular as soon as the bed of the stream became more valuable to the farmer than its water, and no strife would occur; but in most cases there are other interests involved which are antagonistic to this change, viz: the trade in foreign or distant products, the fisheries, &c. Sometimes, too, an arm of the sea which has ceased to be of use to the residents upon its banks, has still a national value as a harbor of refuge or as a thoroughfare.

It might be supposed that a study of long-standing marine works, and the comparison of repeated surveys, would lead directly to generalizations relative to the effects of encroachments upon the pathways of streams. My experience, however, in such inquiries has been anything but this. The testimony, as a whole, is conflicting, and it is only by recognizing among streams generic and specific differences, and classifying all streams according to them, that I have any hope of formulating the results of my study. This hope is not yet fully realized, but I shall venture to suggest a few of the points I have reached.

Tidal and river currents.—Were there no other agencies at work than the tides, the form of channel which these would construct, in alluvial soil, would be the *estuary;* I use this word, because it is already understood to designate a water-way whose sections increase as they near the sea. If this increase of section were simply dependent upon volume, I might have used the term *conoid*, but scour depends directly upon the velocity of currents, and no symmetrical figure can represent a channel excavated by two streams, ebb and flood, which have different velocities and pathways.

1st. *A greater proportion of the scour of channels is executed by the ebb than by the flood, because the former is concentrative, while the latter is dispersive.*

I called attention many years ago to this contrast between the modes of action of the alternate tidal drifts, and illustrated their combined effects by such instances as Delaware and Chesapeake Bays. The tide-wave travels more rapidly in deep than in shallow water, so that in the middle of the bay the water is more elevated on the rise and less elevated on the fall than along the shore; the rise is therefore attended by a current pressing shoreward, while the fall induces a running in toward a central axis. The consequence is, that, although the inflowing and outflowing volumes may be equal, in a supposititious case, the ebb, *concentrated*, is the more rapid, and therefore plays the greater part in excavating a central channel-way to the sea.

2d. *Near the outlet of a tidal basin the section is greater, in proportion to the passing volume, during the flood than during the ebb, so that the latter is the more rapid stream, and confines its work more closely to the channel-way.*

This finds its best illustration in the case where a sandy channel communicates with distant and shallow interior basins. The flood has but little filling to do until a high stage is reached, and does not therefore acquire a high velocity. The discharge, on the contrary, of the interior basins is so delayed that the tide near the entrance has fallen off very much before the outflowing volume becomes considerable. In an extreme case the very volumes that pass up with the entrance channel nearly full escape to the sea again when this channel is nearly empty.

3d. *River currents, because less dense than the sea water, are disposed to become superficial on meeting the latter, and therefore execute little scour in their lower courses.*

The phenomena at the mouths of rivers emptying into tideless seas illustrate in a striking manner this thinning out of the river over the surface of the salt-water. Humphrey and Abbot's report on the Mississippi River states that "the current in the Southwest Pass is quite equal to pushing this material along the bottom, but when the river water begins to ascend upon the salt water of the Gulf, the rolling material is not carried with it, but is left upon the bottom in the dead angle of salt water. A deposit is thus formed whose surface is along or near the line upon which the fresh water rises on the salt water as it enters the Gulf. *This action produces the bar.*"

Admiral Smyth found the waters of the Rhone overlying the Mediterranean three miles beyond the delta shore, but the depth of this fresh stratum measured only three feet.

We cannot attribute the formation of bars exclusively to the lifting of the fresh waters of rivers upon the salt waters of the sea, because there is a disposition in all streams to relinquish their debris wherever an enlargement of section causes a reduction in the velocity of the current, and this, of course, is most conspicuous at embouchures. The waves, in exposed situations, take also a prominent part, not only in breaking up the outflows of streams and in forcing back and heaping up their debris, but often in augmenting the supply of bar-building material by contributions from the wear of the coast. Thus bars are to be found at the mouths of rivers flowing into broad lakes which resemble those upon the seaboard, except that the former are less abrupt and of less elevation than the latter, other things equal. A comparison, however, of coast charts discovers that much the worst bars form where great rivers empty upon tideless seas; so that we may infer that in the meeting of waters a difference of density aggravates the case. All the streams flowing into the Mediterranean are closed to maritime commerce, and all the silt-bearing rivers which find their way into the Black and Caspian Seas are likewise stopped up. According to Sir Charles Hartley, over sixty per cent. of the waters of the Danube escape to the sea by the Killia mouths, over bars having no channels through them more than six feet deep.

River-waters perform so little service as scouring forces at the sea-board, that, in many instances where they have been found charged with sediments, engineers have advocated their exclusion from harbors. The Italian engineers, particularly, concur in advising against the choice of a river mouth as a site for an artificial harbor. So, also, the French engineers, in planning the ship-canal of Saint Louis, have provided for a gate to prevent the waters of the Rhone from flowing into the terminal harbor upon the Mediterranean. Judging from the condition of the natural outlets of the river, they believed that its water, if suffered to pass through the canal, would not only be of no service as a scouring agent, but an injury, because of the burden of mud which it would relinquish upon the threshold of the port.

The Mississippi bars remain at the same absolute elevations during floods as during low stages; and the Danube has a worse bar in the former than in the latter condition. The more effectually a river is able to exclude the sea from its basins, the more utterly impotent it seems to be in its last struggle to reach the ocean. I remember to have been much impressed with the fate of a torrent which I saw rushing from the Maritime Alps toward the Mediterranean. It was a deep stream, plowing its way furiously through the country till it reached the sea; there it received a sudden check, stumbled over its own debris, and broke up.

In my report upon "The Coast of Egypt and the Suez Canal," I called attention to the fact that, with other things equal, rivers with tides have more water upon their bars than those without. The effect of a flood-current is to bring in the sea and mingle it with the fresh river-waters, and thus give to the outflow a deeper scouring power; I may go further, and say that rivers, otherwise equal, have deeper bars in proportion to the amount of flood-current. Is it not a significant fact that the Rhine, with its great outflow of fresh water, fails to maintain a ship-channel to the sea, while, in the same neighborhood, the Scheldt, the Jahde, and the Elbe, have plenty of water on their outer bars?

The river is not in all cases, perhaps not in a majority of cases the world over, the immediate source of the materials forming its bar, but in the present discussion this makes no difference; and I consider the following an authorized

GENERAL RULE.

A river having a bar at its mouth will be injured as a pathway for navigation if the tidal influx is reduced by encroachments upon its basins.

In the above rule I have been careful to speak of the injury as the result of a *reduction of the tidal influx*, because, not only are there rivers where the inflow is nothing, or in small proportion to the rise of the tide, but in all arms of the sea, whether fed by fresh waters or not, the total tidal volume (the prism between high and low water surfaces) exceeds the inflow from the ocean, because it is not high water at the same moment over the whole basin. In the Hudson, for instance, there are two co-existing tides, one of them occupying the space between the sea and Poughkeepsie, the other the reach of the river above. The tide of this upper reach is simply a propagation of the preceding tide of the lower reach. At the moment of high water at the mouth of the river, it is low water at Poughkeepsie, and at this instant the prism (which is wedge-shape, its base being the surface of the previous low water, irrespective of time) represents all that can have possibly flowed in from sea during the entire period of flood. The effect of an encroachment, as measured in reduction of inflow from the sea, is less and less as we go up the river, till we reach Poughkeepsie, where it becomes nothing. The entire tide above this point might be destroyed without lessening the flood-current at the mouth of the river.

In a study of rivers we soon discover that we must distinguish between those which escape to the sea through fiords, and those which form their own beds or break through barriers of sand upon the coast. The former are usually without bars, the latter never. The tide plays so small a part in modifying the original features of the fiord that upon the coast of Maine, where the rise is great, we find harbors and channels resembling very closely those upon the western shore of the Baltic, where there is no tide whatever. It is only the smaller fiords that have filled up with river deposits and with sand washed in by the waves; in most of the larger ones the debris have accumulated only in the sheltered angles and basins. The form of the fiord, expanding its section as it approaches the sea, is favorable to the *gradual* deposit of sediments, whether these are brought down by the river or swept in by the waves. There is, however, no abrupt meeting of fresh and salt water, and no sudden slacking up of river or tidal currents at the sea border, so that outside bars do not often form. In its upper reaches the fiord is often obstructed, because its antecedent inequalities of section have induced the river, in establishing its regimen, to fill in the angles on either side and to raise the bed where the width was great. In such places the diking in of lateral basins, and the contraction of the water-way at some points, may be attended with good results. The history of the Thames shows how steadily the river has improved as the reclamations of its shores have proceeded. The Clyde, also, increased its depth as the levees of rubble were constructed, and without causing injurious deposits elsewhere.* In both of these cases the general form of the estuary was not changed. The walls on the two shores were built so as to diverge from each other, very much as the natural shores had done, except that re-ent~~eren~~t angles and irregularities were covered up. In strong contrast with the good effects of parallel works which we have cited, are the injuries done by bridges and other transverse works, both upon the Thames and Clyde.

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The dikes or dams resorted to for purposes of reclamation belong to two orders, which may be designated as *parallel* and *transverse* works; the former comprising all those which follow along the margin of the stream, the latter those which cross the stream from shore to shore.

Parallel works.—These are of the two kinds, "insubmersible" and "submersible," the former wholly excluding the tides, the latter permitting the overflows for the sake of inducing deposits of sedimentary matter by a process known as "warping."

The general rule we have stated as applicable to harbors having bars must be received with certain limitations, because the degree of injury done by an encroachment depends very much upon the location of the work and its extent. If we compare charts of different sea-ports together, and select those which agree in the yielding character of their beds, in their exposure to the sea, and in their tidal and river volumes, we still find the facilities for navigation unequal, and conclude that the active forces are not equally useful—that some parts are *out of adjustment*. In such cases the way to improve upon natural conditions is obviously to enlarge one basin, reduce another, &c. There are flats too near and others too distant for useful reservoirs; those very near discharge their tidal volumes in advance of the great outflow from above, upon which the scour over the bar mainly depends; and those too distant do not communicate, by the fall of their tide, a motion to the waters at the mouth of the stream till too late for re-enforcement.

The element of distance also enters in another way, viz: the ebb current, flowing off from shallow flats, does not communicate at once its motion to the whole mass of the water in the channel, but for a considerable distance does little more than simply quicken the surface-drift. I have shown this by observations, and am satisfied that high flats near the mouths of estuaries may often be reclaimed without injury to the bar, provided the range of the tide in the river above is not thereby diminished. Those flats are the most useful which discharge their volumes of tide in season for reinforcing the *maximum outflow* upon the bar, and which run dry early enough to prevent a continuance of outflow at the bar after the tide has begun to rise in the sea. As we move up a stream, then the value of flats, in their physical relation to the bar, alters materially, depending upon their elevation from point to point, so that finally we reach so distant a point that those flats only which are covered by the highest spring tides have usefulness as reservoirs of power for the scour of the bar-channels. I would not be understood to say that those particles of water in the reservoirs which themselves reach the mouth of the river in season for co-operation in the scour are alone useful, but those alone whose *transmitted pressure* shall reach the bar and quicken the outflow at the proper stage. Each case presents a problem which may be satisfactorily solved after a proper gauging of the stream.

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* Before dredging commenced.

In Europe the effects of reclamation along the borders of tidal streams have been very far from uniform. The diking-in of marshes, and the closing of canals behind Ostend and L'Ecluse, destroyed those ports, but the diking of the Scheldt has not affected its outside bar, that I can learn. In England some outside bars have been made worse by parallel works excluding tide-water, and this has led the city of Liverpool to guard with jealousy the great reservoir above that city, the filling and draining of which maintains the channel-ways over the bar at the mouth of the Mersey. On the other hand it has been thus far a gain to navigation in many European rivers to fix, by reclamation, the shifting muds and sands near very shallow river mouths, like the Seine, La Vire, the Weser, &c.

Perhaps in this connection I cannot do better than quote the testimony of the highest authority, Thomas Stevenson, esq., who, in his work on the "Design and Construction of Harbors," says:

"From a comparison made many years ago of different low-water sections of the estuaries of various rivers, and also of bays and creeks in their state of nature, I found that *the low-water sectional areas increased directly as the quantities of tide-water that lay landward of each section-line.*

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"The importance of preserving intact the capacity of the upper portions of rivers ought never to be a matter of any doubt, for although it be perfectly true that contraction benefits the navigation at the place where it exists, the effect cannot be otherwise than detrimental to those lower parts of the estuary, including the bar, if there be one, which are in every respect the most important. It has been often proposed that large tracts of land should be reclaimed on the upper portions of rivers, and it has been argued that the channel so constructed will, of course, become deeper than it was before. From calculations subsisting between the low-water sectional areas and the amounts of tidal water lying landwards of the section lines, I found that, in the narrow artificial channel of the river Dee, Cheshire, the efficacy of a given quantity of tidal water was greater than in navigations which were left more nearly in a state of nature. But, as already stated, the effect of excluding water being prejudicial to the lower reaches, ought to lead us to other means of improvement than the erection of such high bulwarks.

"The effect of low-water training-walls which do not confine the strength of the current, but simply guide the first of the flood and the last of the ebb-tide, are now well known from their extensive employment, as, for example, on the Clyde, Ribble, Lune, Nith, and other rivers."

If it becomes necessary in any portion of a tidal stream to improve the depth of the channel, this should be done by first removing the material with a dredge, and then contracting the low-water space by submersible dikes or training-walls. If the locality requiring improvement is low down the stream, so that half-tide dikes will be exposed, while the discharge from above is still active, they will really accomplish as much as levees, and without incurring any injurious loss of tide on the bar. In the Elbe, below Hamburg, there had existed since an unknown period a shoal, which the city finally decided to remove by dredging, and did so a few years ago. This shoal has, however, formed again, and, what is most curious, the new shoal is of sand, whereas the old one was of clay. The case presented was probably that of a neutral spot, where, below a certain depth, the forces (flood, ebb, and river outflows) were in equilibrium. A physical survey would have detected this and saved the waste of labor. In order to preserve an artificial depth, a new direction or energy must be given to the stream by proper dikes. Many persons look at the bar at the mouth of a river as the result of long accumulation and gradual accretion. Lamblardie computed the age of the Trouville Shoal in the estuary of the Seine at three thousand years. My own experience of sandy shoals is that they have no such history; the shifting bottom arranges itself in hills and valleys precisely as the active forces will permit, and a sand-shoal removed by the dredge will be restored almost immediately. I have seen shoals in North Carolina that moved bodily to and fro with every tide, preserving the same height and much the same figure from day to day and from year to year. The attempt of the United States Engineers, many years ago, to cut a channel-way through the bar of Nantucket Harbor, utterly failed; it was like baling out the sea. In studying the sand-banks of New York Harbor, I showed from observations that they lay in the equilibrium points among the tidal currents and waves, and I think most of them would form again in a week if suddenly swept away.

As we have seen, levees are open to the objection that they diminish the tidal influx and reflux; this objection does not hold against submersible dikes or training-walls, which, as far as I can learn, have been equally successful as means of improving the local depths of channels. Notable instances of their success are offered at the Helder, in the Seine, the Thames, the Dee, and in the Clyde.

It is especially in the lower courses of tidal streams that training-walls are effectual. They do not essentially diminish the volume of tidal inflow nor quicken the flood-current. The greatest volume passes into a tidal river after the tide has risen half its height, or when the training-wall is submerged and escapes into the sea again after the tide has fallen below half-tide, so as to uncover the wall, and confine the ebb-stream, now much quickened, to the channel.

In the case of the Clyde, not only were training-walls built *below* Glasgow, but obstructions, caused by weirs and bridges above, were removed or reduced, so that the tide made a longer inland journey. The opposite course was pursued by the French engineers in their attempts to improve the Adour. Upright walls of masory were built on either side of the river, slightly converging as they reached the sea, and the consequence has been a reduction of the tidal range at Bayonne, and no improvement, except that the bar-channel no longer shifts its position. Efforts are being made to carry these walls out beyond the bar of the Adour, but few believe in the ultimate value of this costly work.

The construction of submersible dikes is often resorted to in connection with projects of reclamation, but not always with the design of ultimately raising these works so as wholly to exclude the tide, although the direct object is always to induce accumulation by a process called in England *warping*. In the low countries of Holland and Germany warping is resorted to for the sake of creating fore-shore protection of reclaimed lands. Beyond the main dike a low parallel wall of rubble or fascinage is built, at a distance of a few hundred feet, and the inclosed space divided into pens or catch-basins, to be filled with sediments at the high tide or during river-floods, when these walls are submerged. The Prussian government has provided in this way for the future protection of the dikes in the neighborhood of the naval station at Heppens on the Jahde.*

On the banks of rapid streams, or those subject to floods, fore-shore protections outside of the dikes are absolutely indispensable. These are frequently provided by constructing groynes or jetties of rubble or fascinage, but these are objectionable, not only because they disturb the flow of the stream, creating eddies, &c., but because they are really poor economy, since in the course of time they have to be increased in number till they consume more material than longitudinal training-walls. Weibking says that the experience of many years upon the Rhine has shown that groynes for fore-shore protection must not be more than their length apart. On the Clyde groynes were originally resorted to, but ultimately it became necessary to connect the outer ends of these by training-walls. An exceptional case is offered by the tidal river Tees, where groynes have been used with decided success.

Transverse works.—Weirs and sluice-bridges involve all the objections that we have offered against encroachments upon tide-water, since they completely arrest the progress of the tide. The testimony of history is decidedly against them, and I shall content myself with simply quoting notable facts from the highest authorities to which I have access. In doing this it will not be necessary to distinguish between works thrown across streams for the purpose of elevating the back-waters, and those constructed for drainage, since in their effects upon the lower reaches they do not differ. Bouniceau, in his "Études sur la Navigation des Rivières à Marées," declares that transverse dams ought to be proscribed in the maritime portions of rivers—that "their existence is only injurious to navigation." He cites the cases of the river Aure, which had been shoaled over three feet by the effect of a sluice-bridge, and of the approaches to Isigny, which were sanded up in consequence of a sluice-dam across the Vire. The council of the Ponts et Chaussées recommended the removal of this sluice-bridge, declaring that it had destroyed maritime navigation, because, being furnished with gates, it had hindered the oscillation of the flood and ebb. The obstruction was removed and the tides resumed their good offices as of old. Mr. Cordier, in 1828, wrote the following opinion concerning the effects of sluice-dams above the Port of Dunkerque: "Twice a day the tide inundated the vast plain of Walteringues and twice retired, so that this port was traversed four times per day by an immense current, which opened the channel and maintained the passes from the roadstead. Since the construction of this sluice-dam, natural scour has ceased, and deposits have closed the entrance to the port. The shore, which extends itself more and more, has become continuous, and the passes from the roadstead have shrunk up." Again, with regard to the sluice-dam at Gravelines, the same writer says: "The same movements took place at Gravelines; the sea submerged the territory as far up as St. Omer, at that time accessible to ships, and covered twice a day a plain many leagues square; a broad and deep channel was maintained from Gravelines, and the creek, opened at the foot of the dunes from Gravelines to Dunkerque by the natural scour, favored the navigation and contributed to the amelioration of the two ports; the sluices of Gravelines have changed these conditions, the sea has been held back, the channel is filled up, and this port, formerly very good, is essentially lost."

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* The portion of the Jahde in front of these dikes was the scene of the grand slump in the sixteenth century. Men-of-war maneuver now over the sites of ancient villages and farms.

De Prony favored only a sluice-dam upon the sea-margin, where it should form a continuation of the coast and leave no angle of repose for sands to gather. He had observed that the gravel traveling along the north coast of France rested nowhere except in sheltered angles, the mouths of rivers, &c. I conceive that this distinguished savant had in view only the navigation of the Seine, and believed that if the weir were not placed at the very mouth of the estuary, the sand would so accumulate below that the approach for ships from sea could not be preserved. Precisely this has been the experience at Boston, (England.) Smeaton built the Boston sluice with the expressed design of keeping out the tide-water. In 1720 vessels of two hundred and fifty to three hundred tons (the largest then in ordinary use) could run up and discharge at the quays. Now, in seasons of low river water, the sluice-gate has ten to eleven feet of sand piled up against it on the seaward side. Rye Harbor suffered the same way. A sluice recently constructed on the Nene, fourteen miles from the sea, proved such an injury that the mob tore it up two and a half years after its erection. The sand accumulated below the sluice, but on the removal of the structure was at once swept away by the tide. The old Rhine, passing through North Holland, had been gradually narrowed down by reclamations till its natural outlet could not be sufficiently preserved, even for drainage purposes, and recourse was had to De Prony's plan of constructing the sluice of Katwijk at the margin of the open sea. Commenting upon this, a writer in the "Engineer and Architects' Journal," 1846, says: "The fate of the old Rhine has been aptly compared to that of a dethroned monarch, who is deprived even of the satisfaction of attracting admiration and sympathy by the grandeur of his exit."

The first effects of a loss of tidal volume is usually a narrowing of the channel below rather than a diminution of depth along the channel-way. This seems to have been the experience in Boston Harbor, Massachusetts, and very conspicuously in the North River, Massachusetts. In this latter case an overflow of the sea, during the Minot's gale of 1851, constructed a shingle-bar across the stream about a mile above its mouth, thereby shutting out three-fifths of the tidal volume which formerly passed up. The recent surveys show that as a result of this loss the channel below the obstruction has gradually declined in width, especially at the mouth, while the central depth has remained essentially the same.

The history of the Humber, which upon positive data extends back to 1684, furnishes the most remarkable instance that I can cite of a first-class port that has been damaged in its approaches by loss of tide-water due to reclamations. In the earliest reliable charts, ten, eleven, and twelve fathoms could be tracked in from the sea, and the narrowest place in the approach to the shelter of the estuary was one and a half miles between the five-fathom curves, and no outside shoals existed. Now the principal dangers lie two miles outside of the shelter, where a narrow channel of five fathoms (marked by two light-ships) meanders among shoals of sand. In the interval between the two periods, the original four hundred square miles of tidal area has been reduced to one hundred and ten.* My own experiments in New York Harbor, at the mouth of the Hudson, showed, from sub-current observations, that an increase of fresh-water discharge did not increase but really diminished the seaward scour on the beds of the deep channels; and it was inferred that in the dry season, when the sea-water was carried higher up the river, a deeper flow of the ebb was induced because of the greater density of the water. I have followed the sea-water along the bed of the Hudson forty miles above its mouth.

Physical history of salt-marshes.—In what I have heretofore said of the relations of currents, &c., to the channels which they traverse, I have drawn upon my experience and studies with a degree of confidence; but in the comments which I now propose to make upon the origin of the salt-marshes I enter upon a subject rather new to me, and although I shall still confine myself as closely as possible to the results of observation, I am not at all tenacious of my inductions, but offer them with the hope of eliciting better information upon the subject.

To my mind, the salt-marshes along our coast are not fully accounted for under the terms "*glacial paste*," and *river debris*. They do not appear to me as detritus from the interior, but, in the main, as products of the waste of the coast. It is not only at the mouths of rivers, or at the bases of great continental slopes that these appear, but we find them in coves and dead angles of the shore, wherever the coast is falling back before the dash of the sea; not only upon the borders of the mainland, far from any considerable issue of land-waters, but also upon islands wide out at sea, where there is scarcely any water-shed.

When a headland crumbles down in the attack of the waves, the materials are assorted almost immediately; the coarse sand, gravel, and stones are strewn along to form the *littoral cordon*, but the finer materials are held in suspension till they find opportunity to settle in sheltered places, perhaps under the lee of the cordon itself. Upon our New England shore I distinguish, as the result of this sifting action of the sea, three distinct categories, viz: beech-sand, shingle, and marsh-muds. The separation among these results from their different sizes and weights, which give them different rates of travel along the shore, under the action of waves whose directions are oblique to that of the general coast-line. The angles and coves are cut off and formed into bights, and ultimately into lagoons, by strips of beach which cross them, and upon these strips of beach shingle-levees form at a later period. As the construction of this breakwater progresses, the basin within becomes tranquil, so as to admit of the precipitation of the suspended material forming our third category, and the marsh begins to form under the protection of a natural dike. The littoral cordon thus created has a tendency toward complete closure, since the constructive power of the waves is often out of all proportion with the scouring action of river and tidal currents. These lagoons at best can preserve but narrow outlets, and very often these are closed for long periods—long enough for the marsh to freshen, and, perhaps, become grown over with forests.

The material that would remain suspended only so long as the agitation of the sea continued must be of limited range, and if of uniform character, (quartz sand, for instance,) it must be of almost uniformly small size, because the waves can only suspend those things whose weights are in small proportion to their surfaces. We ought to expect to find in the sediment within the littoral cordon great homogeneity if these are products from the waste of the coast, and we do find that marshes possess this character generally.

Professor Agassiz and others have called my attention to the fact that, at considerable depths under some of the salt marshes, deposits of peat are found. I offer the suggestion that this deposit, antecedent, of course, to the superimposed marsh, is antecedent also to the order of circumstances under which the material from outside has found its way to the same resting-place. I have, in a preceding portion of this paper, spoken of the *narrowing* of harbor channels, which often precedes any central shoaling. Specimens from the most depressed portions of channels often reveal the character of the deposits antecedent to those taking place at the present time. In Boston Harbor, a deposit of peat is said to exist by Mr. Boschke, who has been dredging in the axis of the main ship-channel, where no accumulations within the last century (at least) have occurred.

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* See Shelford on the "Outfall of the Humber," Vol. XXVIII. Proceedings Inst. Civ. Eng.

Upon the beds of quiet basins vegetation plays a constructive part. The *Zostera marina* (eel-grass) arrests and fixes the sediments of the sea very much as the beach-grass catches the flying dune-sands upon the shore. In the *Petite Rade* of Toulon, an elevation of the bottom, two and a half feet in the average in thirty years, was attributed to the luxuriant growth of eel-grass of a species closely allied to our own. We observe the same thing in our own ports, and should expect the filling up of a basin to go on till the whole surface is above the ordinary reach of the sea.

When the subject of reclamation of tide-lands was first proposed to me as a theme, I considered the initial step was to ascertain the elevations of the marshes. This led me very quickly to the discovery that their nearly horizontal surfaces are at the *plane of mean high water*. I compared the marshes on the two shores of the narrow isthmus between Cape Cod and Buzzard's Bays, where we had careful connecting lines of levels and good series of tidal observations. I found that the marshes on either side differed but about one-tenth of a foot from the local elevation of mean high water; so that we have here, within six miles of each other, two systems of marshes, differing in elevation as much as the planes of high water, *i. e.*, the marshes on the Cape Cod Bay side are two and a half feet higher than those on the Buzzard's Bay side. I then inquired into the levels of marshes high up in the Bay of Fundy, and computed, from some levelings made by the Royal Engineers, that the plane of the marshes lies about half-way between the high waters of springs and neaps, or at the mean high-water plane. So, in San Francisco Bay, as well as I could judge from a short series of observations, the marsh-plane is the ordinary high-water level. It appears, then, that the sea has exercised an important control upon the marsh, and this is circumstantial evidence that these marshes belong to the present tidal epoch, and that the sea has played an intimate part in their formation.

Leaving out of the question the deltas of rivers, it is a fact, well known to practical engineers, that deposits of sediments take place in harbors and docks, and that the amount accumulating in tidal waters is much greater than elsewhere. According to Minard, (as cited by Stevenson in his work on harbors,) the sedimentary deposit in basins along the almost tideless shores of the Mediterranean, is not one-sixtieth part as great as in those similarly situated on the Atlantic and North Sea.

This testimony of Minard is, no doubt, an exaggeration, because it is based upon docks, &c. If channels alone were compared, the results would ~~have~~ been quite of an opposite character. In tidal harbors the deposits are not uniformly distributed over the bottom; the channel-ways are swept out by the currents, and the angles of the shores filled up. My own comparison of the charts of the Mediterranean with those of tidal seas confirms me in this view, and I can but regard the tides as exceedingly valuable agencies in preserving the avenues of navigation. In some of our ports, in New York, for instance, channels that are hourly traversed by steamers are gradually deepening, because the bottom is stirred, so that the tidal current can bear away material which it could not otherwise lift.

Let us now inquire if there is any evidence that the marshes are increasing, and whether this increase is particularly striking in neighborhoods where the coast is wearing away. I could furnish some small instances of growing marshes in our own country, but I think it safer to refer to the changes in the Old World, where the comparative surveys cover several centuries, and where remarkable cases have attracted observation. To European engineers the increase of certain marshes is a fact so well recognized, that methods have been devised by them for lending aid to nature in this formation of new lands. These methods are known in England under the general designation of "*warping*," which I have already referred to under the head of "parallel works." In comparing the results reported by engineers of different countries, I was not surprised to find that the success of warping near the coast has been very unequal in different localities, and that, with other things the same, it is greatest in neighborhoods where the coast is falling back. Warping is employed in Holland to add fore-shore for the protection of the dikes, but would not pay simply as a means of reclamation in the mouths of the Rhine, where the yearly deposit is but a thin film. In the estuary of the Humber, on the other hand, the warping is wholly for the enlargement of agricultural districts. For distances of forty miles above and below the mouth of this stream, the coast has fallen back ten feet per year, according to the different surveys since 1684, which represents an enormous volume, because the coast is generally high, (thirty to forty feet.) The recent growths of the marshes in this estuary are attributed to material from outside by Professor Philips in his "Geology of the Yorkshire Coast," and seems to be the only reasonable way for accounting for such enormous deposits at the mouth of so small a river. For instance, Sunk Island, near the mouth of the estuary, which, in the time of Charles First, contained nine acres of diked land, now has seven thousand acres under cultivation, and covers the site of a twelve-foot channel as given on several early charts.* The warping practiced in this estuary accomplishes generally one foot of elevation per annum, although Coleman's "European Agriculture" mentions a case of "ten or fifteen acres warped to a thickness of one to three feet during ten to twelve tides." I find in these accounts of the Humber estuary that the greatest deposit within the submersible dikes is during the dry season. This I consider a significant fact, indicating that in proportion as the flood-current (bringing sediments from outside) is of long duration, the warping succeeds. Ferdinand de Lesseps, in one of his early reports,† attempted to discredit the ancient idea that *the delta is the gift of the Nile*, and in this absurd endeavor he cited some collateral evidence which serves my turn better than it did his. An analysis of the deposits in the Bay of Saint Michel shows that the material is from the adjacent coast, which is retreating. An examination in the Seine showed that the river debris did not extend below Rouen, and that the shoals forming in the estuary below were from the wear of the coast.

Warping is practiced with success at the head of the Bay of Fundy, where extensive marshes have been reclaimed. The flood tidal current brings with it great burdens of mud. Here the narrow isthmus affords no considerable water-shed, and the water evidently owes its turbid character to the rush of the tide along its bed, and to the wear of the shores below. Even at our southern inlets, where the sifting operation would seem to be finished, and where the cordon would seem to have reached a state of equilibrium, the flood-current and the water pushed in by the rush of the sea is often milky with the quartz-dust which the grinding breakers supply. From the very nature of the flood-current (divergent) it presses upon the coast and receives for transportation all the waste of the shore, and all the fine material ground up by the breakers. The "bulkheads" within our southern inlets seem to be composed of the fine sand brought in from outside, while the outer bar is but the mass of material from the site of the inlet itself. In some of the lagoons of the Mediterranean shore, warping is practiced upon waters that flow in from the sea.

Along some coasts there is a mass of material traveling along shore and ready to seek rest in any cove or shelter, especially where encouraged by the flood-current, which, as I have said, is eminently a coastwise stream. Lieutenant, now Admiral Davis, first called special attention to the constructive character of the flood-current, in his articles before the American Academy, upon which I shall hereafter have occasion to comment.

According to Bouniceau, (*Études et notions sur les constructions à la mer*,) to bring the strand to the level of high water by warping, requires twelve years in the estuary of the Seine, thirty in the bay of Vays, and eighty in the Sheldt.

The littoral cordon is a developing physical phenomenon of the coast, distinguishing peculiarly, I think, the present geological period, and perhaps the most interesting and important among the changing features exhibited by our comparative surveys. It appears upon our New England coast as isolated strips of beach or shingle levees, crossing the mouths of fiords and coves; but upon our southern sea-board it is the grand characteristic, and is almost continuous from Montauk to the coral reefs of Florida, and from St. Marks to Yucatan.‡ Except at Long Branch, I can remember no locality below Montauk where the antecedent drift-formation reaches the sea, and I conceive that those long rifts, like Hatteras Banks, which lie many miles from the main-land, occupy what was (perhaps at the time the glaciers melted) the breaker-line upon the shallow bank which formed the submerged prolongation of the continent, which has here but a slight inclination toward the ocean. This windrow of sand I believe to be very gradually falling back; the fine sand ground up by the sea is caught up by the winds and formed into dunes, or forced through the inlets by the rush of the waves and flood-current, to be converted into flats and marshes.*

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* Shelford.

† "Percement de L'Isthme de Suez. Exposé et Documents Officiels, 1855."

‡ Although the reefs of Florida may be similar formations, veneered with the coral growth, the proof is wanting to sustain this conception.

The tendency of the natural forces now operating upon the coast seems to be toward a complete smoothing away of all the indentures of the shore-line. I use the word *indentures*, because I would not imply that great bends and gulfs are to disappear. We are naturally prone to the belief that what we call the orderly activities of nature are working out an equilibrium, and this has induced a prevalent notion that the sea is robbing the continent of material to fill up the inequalities of its bed. As far as my observations have extended, there seems to be little ground for this notion, and I am inclined to think with Rear-Admiral Davis that the sea "ejects or repels" the débris of the continent that would fall into its bosom.† I do not agree with the savan whose words I have quoted, in giving to the flood-current the principal part in the "ejection" of materials, and it seems to me that the evidence he cites bears witness rather to the action of waves than to that of running water. It is a familiar fact that waves running over shallow ground acquire a real motion of translation. The passing of a wave as felt by divers, standing upon the bottom, is a sudden jerk toward the coast. The water that would thus pile up against the shore is carried back into the ocean by a general and continued current. The movement toward the land is in very short but very rapid dashes, while the return is more gentle and steady. In this contrast of velocities between the onset and the retreat of the sea, lies, I think, the true cause of the accumulations upon the coast and the tendency of heavy bodies, like the coal from steamers, &c., to come on shore. When we consider that the *work* done is proportional to the *square of the velocity*, and that the *weight* that may be moved by running water varies with the *sixth power of the velocity*, we certainly may expect the changes along the coast to reflect rather the action of rushing waves than feeble currents. My own observations along the coast of Long Island showed that an eastwardly current prevailed, but that the sands near the beach moved before the sea to the westward. Under circumstances arising from the peculiar configuration of the shore, or from its exposure, the waves at some points along the coast are prone to run very high, and develop great transporting power. It is particularly noticeable that gulfs and bays which open in the direction from which heavy gales frequently blow, are extending without any diminution of average depth along their axial lines, except where rocks resist for a while the wear of the sea. As an example, and a good one, because resting upon positive knowledge, I offer the case of the Gulf of Gascony in the neighborhood of *St. Jean de Luz*, where repeated surveys show that the submerged contours are falling back, and the bay actually extending and deepening. The material scoured away is ground up fine by the waves, cast upon the beach, and finally blown away in dunes toward the interior.‡ The bight of Cape Cod Bay below the Plymouth Entrance bears every trace of an encroaching sea. The water is bold close in-shore, so that a man-of-war may ride at anchor within what was probably the base of the high hill, whose remaining portion bears the name of Peaked Bluff. The waves have carried none of the material seaward, (of this we are sure from the character of the bottom,) but have swept it along shore to the eastward, the fine sands to be formed into dunes, and the shingle to be moved on and accumulated until it shall become equal to the protection of the shore by resisting the onset of the sea.

I have not, in our repeated surveys, seen the slightest evidence that the material of the falling bluffs of Boston Bay are borne out to sea; I think the harbors and coves have received it all. The ebb-tidal currents seem to have kept the channels sufficiently free, and may have carried out to sea some very light substances, but we do not find them deposited there.

In addition to the erosion which great tides induce, the wedge shape of the Bay of Fundy is no doubt peculiarly favorable to the augmentation of the carrying powers of ordinary waves driving in from the sea, and to these combined actions I attribute the turbid state of the waters near the head of this gulf, where the tide is so laden with sediments that warping is successfully practiced.

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* I am indebted to Colonel Grammar, of the Massachusetts Harbor Commission, for positive data relative to the falling back of Hatteras Banks.

† See memoir of Lieutenant Charles H. Davis, Fourth Volume, (new series,) American Academy of Arts and Sciences; also, Smithsonian Contributions of 1851.

‡ From a lithographic copy of a report furnished to me by the author, Boquet de la Grye, hydrographic engineer of the west coast of France.

Mr. A. Savary, an engineer residing at East Wareham, has written me an able and very interesting communication concerning Buzzard's Bay, in which he gives me the results of observations, some of them stated numerically, which show that the sheltered basins at the upper end of the bay are filling up with sand and stones torn from headlands below, which are wasting under the action of the waves during southerly gales. Some of these basins, he says, are used for planting oysters, and, from his own experience, states that after a gale the oysters are always found higher up the stream. He, however, attributes this movement altogether to the flood-current,* and makes it dependent upon the depth of superincumbent water, a conclusion that seems to be opposed to well-established laws of hydrodynamics, although I am aware that some English engineers of eminence, among them Mr. Calver, still insist upon making *weight* an element in the friction of running water.

The views I have entertained relative to the restoration to the continent of all the material washed from its bluffs and headlands by the sea, must be modified when we come to consider islands. Where these are crumbling down under the action of the waves, we usually see a loss upon the windward shore, and a reappearance of the material upon the leeward side. Sometimes we find two hooks extending leeward from either end of a wasting island, as in the case of Nantucket, and these hooks, in other cases, unite under the lee and inclose lagoons, which ultimately become, perhaps, marshes. High islands may thus gradually be converted in low atolls, (if I may use this term,) which occupy more than their original share of the ocean bed. There are, however, many cases where the wasted material does not reappear, most prominent among which is the familiar instance of Helgoland, a lofty island, which was once many times its present area.

A fringe of salt-marsh is sometimes seen along the coast, outside of the littoral cordon, showing that the latter has been forced back over the marshes formerly lying within its protection; and, as this outlying marsh is seen only at very low tides, in most cases, it has been cited as an evidence of a general submergence. I suggest that the falling back of the heavy natural dike over the marsh may have depressed the latter, or where this has not occurred, that the sea has undermined the marsh and let it down. No earthy material resists the action of the sea better than salt-marsh; but below the vegetable soil, at a considerable depth, there is often quicksand that might easily be washed out by the sea. I know of an instance where a very high dune, in falling back from the coast, left exposed beneath the sea an old salt-marsh, upon which it had been resting for many years, and which it appears to have crushed down by its weight. On the other hand, the shingle-levee on the Scituate shore does not depress the marsh as it rolls back over it, although the weight is over 1,500 pounds to the square foot.

After inclosure and drainage, salt-marshes usually sink, sometimes largely by their own weight, where the substratum is peat or quicksand, and sometimes only the amount due to shrinkage. Slumps of twelve feet have occurred in Holland. The Bisch-Bosch, and a large part of the Zuyder-Zee, lie over ancient folders. It may be that marshes have sometimes dried up and sunk after the natural closure of the "littoral cordon," and again, after a long period, have been exposed to the sea by the destruction or falling back of the cordon. I have seen no case of submerged marshes that seems to me to be worth much in support of a theory of general submergence.

Most of the marshes along our coast, like those of the Netherlands and the west coast of Denmark, lie within the "littoral cordon;" and in the course of the practical operations of the past season, which form the subject of the second part of this report, I have been led into special studies of the shingle-levees. These natural dikes have some characteristics which are general and deserving of comment, I think, aside from their particular bearing upon projects of reclamation.

Shingle-levees.—English observers are pretty well agreed upon the following characteristics of shingle-levees:

1st. The largest pebbles are found upon the summit and farthest from the source of supply.

2d. The fore-slope is a series of "fulls" or berms.

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* Very much the same view that was expressed by Lieutenant Davis.

To these rules or general points of resemblance, my own experience adds the following:

3d. The seaward slope, near the crest, is 3 : 1, while the mean is 5 : 1.

4th. While upon the one hand the fore-slope is diversified by *horizontal* fulls or berms, the rear-slope, in striking contrast, is an alternation of *vertical* furrows and buttresses. The front face takes the form best calculated to resist the attacks of the sea, while the rear side takes the form best adapted to the rapid escape of overflowing water, as far as this is consistent with the security of the base.

The best explanation that I have seen of the first rule above stated is implied in the following quotation from Palmer's paper in the Phil. Trans. of 1834: "In all cases we observe that the finer particles descend the whole distance with the returning breaker unless accidentally deposited in some interstices, but we perceive that the larger pebbles return only a part of the distance; and upon further inspection, we find that the distance to which each pebble returns bears some relation to its dimensions."

The sea, in its onset, is an irresistible force, which, upon its sudden destruction, would leave a wall of stones, mingling all sizes and weights indiscriminately. The reflux or *undertow*, however, carries back the smaller stuff, and forms with it a talus slope. We see, then, that the average size of the stones should be greater near the top, and that the fore-slope should be less and less steep as we go down to the foot. It has been suggested that the breaking sea is an explosive force, and that, therefore, the larger stones should go further than others; but my observation has been that there is no assorting process in the breaker, but simply a *selection* in the recoil.

If the height of the levee is in proportion to that of the storm-sea, we should expect that the slopes of all levees of the same material would be in the same order under the above theory, and this is my experience thus far in this study. The slopes are those of repose in running water.

Caland constructed the great dike of West Capelle under the conviction that the action transmitted by the shock of the waves should vary with the square of the height of the water covering the talus, and that the base of the fore-slope of a dike should be in proportion to the square of the height.* I cannot find in nature any rule of construction like this. In the comparison of shingle-levees of different heights, I find the slopes constant; in other words, the base of the fore-slope varies with the first power of the height.

I find from my notes that on the occasion of my visit to Petten, North Holland, Mr. Conrad was busy in pitching the fore-slope of the great dike with basalt blocks at slopes of 3 : 1 and 5 : 1, but in the reverse of the natural order, *i. e.*, he placed the steeper slope below the other. This seems to have been a form arrived at from several centuries of recorded experience.†

The fulls or berms, which appear upon the seaward face of the natural dike, are miniature levees, thrown up by the lesser storm seas and superimposed upon the main structure. They add to the security of the dike, since they serve to break up the sea. It is a fundamental idea, already fully recognized by engineers, that the difficulty and cost of building a wall that will resist at once the dash of the breakers, is out of all proportion with the facility with which the attack may be resisted by a succession of obstacles. I was shown, in 1868, an artificial structure in the form of a *stairway* upon the shore of Medoc, which was said to have withstood the shock of the great seas of the bay of Biscay better than anything yet devised. So, also, as a parallel to the form of the rear-slope, I find in the cuts of railways that the sand-banks on either hand do not reach the conditions of proper drainage and repose, so as to be permanently covered with grass, till corrugated or furrowed vertically, and I have seen cases in France where the skillful engineer, anticipating the slow processes of nature, put his slopes at once into this permanent form.

Other natural levees.—The general rules I have laid down apply to *shingle*-levees exclusively—that is to say, to those levees which are composed of stones rounded and water-worn. Occasionally levees of angular stones are met with upon our coast, and I have seen them in the Bahamas composed of shells, and on the lake shores of drift-wood. The slopes and heights vary with the different materials in a manner that I do not yet understand. At Nahant there is a short levee of angular blocks broken from a projecting ledge near by, the largest pieces being at or near the summit, where they occasionally measure over three cubic feet each. The height of this levee is about 0.75 of that of the shingle-levee in the same neighborhood, and its fore-slope is less abrupt. Professor Agassiz has furnished me with evidence of the very recent origin of this levee, which I shall quote hereafter.

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* *Essai sur les Travaux de Fascinages, par U. N. Kümmer.*

† See *Verhandeling over de Hondsbossche Zeeweering door I. F. W. Conrad, Ingenieur de I ste Klasse van's Rijks Waterstaat.*

Perhaps the most singular freak of the sea in the way of dike-building is to be found upon Salt Key, one of the smallest of the Bahama Islands. Here occurs an almost perpendicular wall, about twelve feet high, consisting wholly of *conch-shells*, nearly all of them perfect. One might suppose from the uniform height of this wall, and its perfect alignment, that it was a work of art, except that to build a "dry wall" of conch-shells would rather puzzle human ingenuity.*

In my past season's work I have measured several levees, for the purpose of ascertaining how high the seas run upon the coast; the overflow of these being rare and notable circumstances to the persons in the neighborhood. In the second part of this report I have given the elements for profiles of sections. The fore-slopes, where the material is shingle, have been 3:1 for maximum and 5:1 for mean.

The highest shingle-levee in the world is Chesil Bank, on the south coast of England, in a situation peculiarly exposed to the violent seas that rush into the channel. Its height varies from twenty-three to forty-three feet along a distance of ten miles. The inclination of the fore-slope in the most perfect part of this levee is 5:1.

Upon the borders of the Bay of Audierne, in Brittany, there is a shingle-levee nearly eight miles in length, whose average height is sixteen feet—the same as our levee at Scituate, and, like the latter, its seaward face is a series of berms. The fore-slope is 3:1. "The shingle-levee," says Beaumont, "when viewed as an isolated phenomenon, merits but little attention, but in its relations to other phenomena we recognize that it has a great influence upon a crowd of important facts." I think, as a rule, the shingle-levee, as such, cannot be traced below ordinary high water, so that it is decidedly a *storm-record*. With no desire to involve myself in the discussion of wave theories, I must state one point, because of its bearing upon my general subject. The positive and negative, or *crown* and *hollow* portions of a storm wave, are of unequal height, so that the rise above the sea-level (plane of equal volumes) is considerably greater than the fall below. Many shoals, whose depths given upon our charts are less than half the range of ordinary storm-waves, have never been seen exposed in the trough of the sea. Some years since a heavily laden ship, drawing about eighteen feet of water, was driven by an easterly gale across several of the Nantucket shoals, upon which, according to our maps, the depths scarcely exceed eleven feet. She struck heavily many times, but the leadsman never called less water than the chart indicated. Standing upon the beach during a heavy storm, one rarely sees, as the waves retire, much more of the strand than in ordinary weather; and Robinson Crusoe's thrilling account of his race for life across the floor of the ocean, during the recoil of the sea, disturbs our confidence in him at the outset of his narrative.

The dikes along the coasts of Europe may be said to furnish limiting measures of the heights of overflows not wholly local in their significance. Until a comparatively late period, the sea-dikes in Holstein and Schleswig were raised but ten feet, and in Holland but ten to thirteen feet above ordinary high-water mark. Modern engineers, however, have carried these works to greater elevations. On the Schleswig coast, eighteen and a half feet above the highest spring tides is regarded as entirely safe.† On the Dutch coast, after a recorded experience of four hundred years, the grand dike of Petten has been carried up to twenty-one feet above ordinary high water,‡ and upon the Mediterranean shore of France sixteen and a half feet is proposed for new works.§ As the injury suffered by sea-dikes has been principally due to the rush of water down the landward slopes during overflows, it has been deemed prudent to raise the crest of the most exposed and important works to the extraordinary heights I have stated.||

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[*] Reported by myself in 1867.

[†] Testimony of Captain Carstenson, dike inspector, cited by J. Paton, M. Inst. C. E.

[‡] From a diagram entitled "Scituate der Pettimer Zeeweering," furnished me by J. F. W. Conrad, engineer of the Waterstaat.

[§] Ponts et Chaussées, Department de l'Herault, report of the engineer-in-chief.

[||] The highest dike that I call to mind is that of West Capelle, over twenty-six feet above the tide.

Breakwaters do not furnish what I have termed "limiting measures," because many of them have been built with the expectation that storm-seas would leap over them, while others have been carried high for the sake of *weight*. Although most of the breakwaters have been built in situations already partially sheltered, there are instances where they have been more exposed than the adjacent coasts.

PROFESSOR PEIRCE'S CRITERION.

This is a rule for deciding upon the propriety of attempting to reclaim the marshes of a tidal river by the construction of a transverse sluice-dam. It was offered expressly for a guide in the cases before the Massachusetts Board of Harbor Commissioners, and finds its place properly in this portion of my report.

"*Draw a tangent to the tidal curve at the point where the tidal current changes from ebb to flood; if this tangent intersects the descending branch, the reclamation will preserve from overflow all the land which is higher than the point of intersection.*"

In explanation of the above, it is simply necessary to state that the river supply is regarded as uniform, and therefore to be represented upon the diagram as a straight line, which will, of course, be the prolongation of that which represents the rise at the moment of *slack-water*, when the outflow and inflow are in equilibrio. If, as is usually the case at the mouth of a river, the observed curve is nearly that of the sines for a circle whose radius is half the range of the tide, reclamation is possible if the flood-current begins to run up *within* one hour and forty-three minutes after the time of low water. If slack-water occurs at the instant of low water stand, drainage of the marsh to a depth equal to the range of the tide is practicable; but if the flood-current does not commence to run up until one hour forty-three minutes after low water, the fresh-water accumulation, while the sluice-gates are closed, will equal the range of the tide. Fig. 2, of Plate No. 27, illustrates these two cases.

Care must be exercised in the application of this rule in certain cases: 1st. When the stream has a transverse bar rising above the plane of low water, the observations used must be those made upon the bar itself. In the instance where a "submersible" dam exists, the rising curve *within* the obstruction resembles that observed outside, except that the lower portion to the height of the dam is cut off. If, for instance, the dam is elevated to the height of half tide, no tangent to the tidal curve within will intersect the descending branch, and yet the case may be one of possible drainage to an adequate depth. In Fig. 3, I offer curves plotted from simultaneous observations near Hyannis, Massachussetts, in which the larger tide is that of the harbor, and the smaller that of Dunbar's Salt Pond, which is separated from the harbor by a natural bar, considerably elevated above the plane of low water outside, although never dry. No fresh-water feeders exist, and drainage to the level of the bar is of course possible, although the criterion (misapplied to these curves) would say not. 2d. This rule is inapplicable, I think, to an inlet communicating with a great lagoon, because in this case, even in the entire absence of fresh-water feeders, the current epochs will be late.

PART II.—FIELD-WORK.

At the request of the Massachusetts Board of Harbor Commissioners, you instructed me to examine the marshes and shores of Scituate and Marshfield, to determine the practicability of reclaiming the tide-lands, and to ascertain the probable effects of reclamation upon the navigable facilities of North and Green Harbor Rivers. In these studies I have pursued my usual custom of including in my examinations all the features of the coast which properly belong to a physical survey, so as to make this work a part of our general scheme of a physical history of the seaboard.

GREEN HARBOR RIVER.

This *river*, so called, is the drain of about fifteen hundred acres of marshes, situated mostly in the township of Marshfield. It receives two considerable tributaries and innumerable brooks and creeks in its meandering course. The lower reach of the river is known as Green Harbor, whose length from Turkey Point to the bar is about seven-eighths of a mile, and whose maximum low-water width scarcely exceeds five hundred feet. A sand-bar obstructs the entrance, upon which there ~~is~~ are from two to three feet of water at ordinary low tide. The average rise is nine feet, and vessels can take the ground within the harbor at low tide without injury. The shelter from winds and sea is good. As far as I could learn the trade of the place employs but one small vessel, but during the summer, many small yachts, for the accommodation of watering people, make here a rendezvous. It is not entitled to the slightest consideration as a port of refuge, although vessels have been known to run into it under desperate circumstances.

It has been proposed to reclaim the marshes by constructing a transverse sluice-dam at the head of the harbor, and I visited the scene during the month of June, with the two-fold object of determining the practicability of this reclamation, and the likelihood of resulting injury to the entrance. The problem of reclamation presented is one of the simplest kind, and I was enabled to reach a positive result from a few experiments and a very limited survey; but the question of injury to the entrance has perplexed me very much. I shall offer, however, an argument upon this point.

The place chosen for gauging the river was near Turkey Point, where the uplands approach the stream on either hand, and where a dam could be most economically and effectively constructed. The table which follows furnishes the elements for a profile of the section from upland to upland crossing the river at the place of gauging. (See Fig. 4.)

The tide was observed for thirteen hours upon the 30th of June. The range was 8.90 feet, which is about what I should compute for Cape Cod Bay at the same age of the moon, and no unusual distortion of the profile could be detected. The marshes are at the level of high water in this portion of the basin, and supposing, at the date of our observations, gates to have been closed upon the river at the time of low water, the accumulation behind them during the following six hours would have been, according to your criterion, about three feet, so that the surface of the marsh would have been six feet above the water-table at time of high water in the bay. This depth of three feet is largely in excess of the fresh-water supply, because many of the creeks do not fully discharge their tide-waters during the fall in the main river. Our hydrometer, at low water, gave a density of 1.0195, indicating that the out-flow was then three-quarters sea-water. Indeed, the current observations show that the fresh-water discharge was exceedingly small, and that gates of ordinary dimensions may be relied upon for draining this basin perfectly in summer.

The river, at its embouchure, flows into the sea in a course but little to the eastward of south, with rocks upon its left and sands upon its right bank. These sands, driven by the waves and the flood-current, are constantly invading the river's mouth, but are driven back by the out-flow, and the bar is for the most part formed of material from outside, which is left in the debatable district between the opposing forces. I think that it is only during heavy weather that the flood-current, aided by the waves, can overbalance the scour of the ebb, even during dry seasons, when the fresh-water outflow is itself too small to be considered, and I base my opinion upon the following considerations: The shifting material is sand, and this is not suspended, but rolled or driven along upon the bottom at a rate far less than that of the water itself, so that the progress that it ultimately makes, and the direction it takes, must be determined by the power and direction of the resultant of the forces, precisely as if these forces acted simultaneously. Now, although the flood and ebb, at low-river seasons, are essentially the same as regards volume, they are quite unlike as regards velocity, *i. e.*, working-power. The veins and arteries of the marshes are filled late and drained late as regards the tidal time at the mouth of the river, so that the greatest in-flow is called for when the water is high upon the bar, while the greatest out-flow is so much behindhand as to reach the bar when the latter has but a small section; the former, therefore, creates but little horizontal motion, while the latter creates a rapid current. When we consider that the *work* of a stream increases with the square of its velocity, we should not be surprised to find the ebb at the mouth of a river playing the dominant part in the excavation of channels. For instance, when the tide at our station had risen two feet, or less than one-fifth of its range, the velocity of in-flow was 0.50 feet per second, but when it had fallen to the same stage, the outflow was 1.40 feet; in other words, the working-power in the same section was *eight times as great upon the ebb as it was upon the flood.* If a sluice-dam were to be constructed, shutting out the tides from the marshes, the fresh-water out-flow only would be left to resist the action of the waves, and, as far as I can judge, the summer discharge would be impotent. In the introduction to this report I have pointed out instances of little harbors that have been injured by weirs and dams like that proposed for Green Harbor River, and I have little doubt that a decline in the depth on the bar will follow the reclamation of the marshes. It is true that the direction of the embouchure is favorable as regards shelter from the sea, and that the supply of material is not so great as at many other points along shore, but I have about made up my mind that in course of time, after the dam is constructed, the inlet will become a "tide-harbor," like Scusset and Sandwich, *i. e.*, dry at low tide, at least upon its bar.

Section of river at Turkey Point, (Fig. 4.)

Distance in feet.	Height above low water of June 30, in feet.	Remarks.	Distance in feet.	Height above low water of June 30, in feet.	Remarks.
0	13. 46	Upland, left bank.	835	9. 34	On island.
36	12. 29		838	9. 17	On left bank of main stream.
59	10. 00	Edge of upland.	856	1. 60	River bed.
131	9. 61	Marsh, salt grass.	858	0. 20	Do.
196. 8	9. 33		868	—4. 2	Do.
262. 4	9. 01	(Plane of high water = 8. 90.)	878	—5. 8	Do.
318	8. 63		888	—4. 9	Do.
393. 6	8. 74		898	—6. 0	Do.
459. 2	8. 99		908	—6. 2	Do.
524. 8	8. 62		918	—6. 3	Do.
557. 6	8. 99		928	—6. 9	Do.
590. 4	8. 47	Left bank of stream.	938	—6. 2	Do.
600	2. 4	River-bed.	948	—6. 1	Do.
610	1. 4	Do.	958	—5. 4	Do.
620	0. 6	(Plane of low water = 0. 00.)	968	—5. 0	Do.
630	—0. 3	Do.	978	—2. 1	Do.
640	—0. 3	Do.	988	—2. 2	Do.
650	—1. 0	Do.	998	—2. 2	Do.
660	—1. 1	Do.	1, 008	—1. 2	Do.
670	—1. 1	Do.	1, 018	—0. 4	Do.
680	—1. 1	Do.	1, 028	0. 2	Do.
690	—1. 1	Do.	1, 038	0. 8	Do.
700	—1. 2	Do.	1, 045	1. 6	Do.
710	—1. 2	Do.	1, 088	4. 05	Right bank of main stream.
720	+0. 7	Do.	1, 137. 4	8. 61	Marsh.
730	8. 59	Right bank of stream.	1, 186. 6	9. 45	
772. 6	8. 88	On island.	1, 207. 2	10. 40	
798. 6	8. 65	Do.	1, 269	11. 11	Turkey Point, bushes.

NORTH RIVER.

Dean's History of Scituate published in 1831, furnishes a brief description of the North River, which I shall quote, not only because as a general sketch it is still sufficient, but also because it comments upon the facilities for ship-building and navigation which the river afforded before the recent disastrous inroads of the sea:

"This stream received its name before 1633, and probably from the circumstance that its general course is from south to north, or that it was farther north from Plymouth than South River in Marshfield, which meets the North River at its mouth. The North River is a very winding stream, flowing through extensive marshes, sometimes, as it were, sporting in the broad meadows in the most fanciful meanders, and sometimes shooting away to the highlands which border the meadows. There is one reach which has long been called the 'No Gains,' from the circumstance that, after flowing from side to side, and almost turning backward for several times, it has, in fact, flowed several miles and gained but a few rods in its direct progress to the sea. From the sea to the North River bridge, on the Plymouth road, an air-line would not exceed seven miles, while the line of the river amounts to eighteen miles. The tide rises at the North River bridge from three to five feet, and there is a perceptible tide two miles higher up. It has three chief sources, the Namatakeese and Indian Head, which flows from the Matakeeset Ponds in Pembroke, and the Drinkwater, which has its sources chiefly in Abington. The tributaries are the three Herring brooks on the Scituate side, and the Two-Mile Brook and the Rogers' Brook on the Marshfield side." * * * * "Just below, and at an air-line distance of a little more than three miles from North River bridge, is Union bridge. A half mile lower, on the Scituate side, is King's Landing, and about half a mile on the same side is Hobart's Landing. Here, we believe, the first vessels were built, by Samuel House, as early as 1650." * * * * "Here the ship Columbia (Captain Kendrick) was built by James Briggs, A. D. 1773. It was the first ship that visited the northwest coast from this country. Captain Kendrick explored the river Oregon, and named it from the name of his ship, which name will probably prevail henceforth. At the distance of another half mile below is Little's bridge, at which point we believe vessels have been built on the Marshfield side. The meadows above this station are of very various width, in few places exceeding a mile; but below there is a wide expanse of marsh, anciently called the 'New Harbor Marshes.' The scenery here is on a sublime scale when viewed from Coleman's Hills, or from the Fourth Cliff. The broad marshes are surrounded by a distant theater of hills, and the river expands and embraces many islands in its bosom. Here it approaches the sea, as if to burst through the beach, but turns almost at right angles to the east, and runs parallel with the sea-shore for nearly three miles before it finds its outlet, leaving a beach next the sea for nearly twenty rods in width, composed principally of round and polished pebbles, excepting only the Fourth Cliff, a half mile in length, which comprises many acres of excellent arable land. Nearly a mile above the river's mouth is White's Ferry, where is a wharf and a small village on the Marshfield side. Here vessels have been built, and many that have been built above here receive their rigging. The river's width may be estimated as follows: In ordinary tides, at Union bridge, seven rods; at Little's bridge, nine rods; it expands below to a half a mile in width, where it is now called Fourth Cliff Bay, and formerly New Harbor; here the channel divides, and unites again a mile below; a half a mile above its mouth it is fourteen rods in width. The channel at its mouth often shifts its place, owing to the nature of the sandy bottom and to the violence of the stream and the tides. It seldom affords more than nine feet of water, even when there is but one channel; but it often happens that there are two channels when the water is something less. This fact accounts for the difficulty and expense of carrying out the vessels built upon this river; and yet only in part, for there are shoals above over which vessels of two hundred tons and upward must be lifted with gondolas or heaved with kedges. The principal are Wills' Shoal, at the upper part of the New Harbor Marshes, and the Horseshoe Shoal."

Since the above statement was written forty years have elapsed, during which important physical changes have occurred, which, in connection with other circumstances, have led to the abandonment of nearly all commercial enterprises upon the North River; and the project now entertained for reclaiming the marshes, by sluicing out the tide, involves the sacrifice of no important interests of navigation.

The injuries which the channel-way has suffered have been principally due to the waves, which, during violent storms, have burst through the narrow strip of beach that separates the lower reach of the river from the ocean. Appreciating the importance of this natural dike in connection with the projected reclamation, I devoted some time to its inspection, with a view to pointing out its weak places. With the exception of Fourth Cliff, which appears to be the smaller portion of a high hill, once extending into the sea, the entire beach is but a windrow of sand and stones cast up by the waves and subsequently modified in part by the winds, differing only in matters of detail from the *littoral cordon* of our Southern States.

Shingle-levees.—A portion of this beach is permanent, the forces which created it having, as it would seem, ultimated their effects. I refer here to the shingle-levee, which, from the point where the stream "*approaches the sea as if to break through*," extends like a strong bulwark half way to the river's mouth, interrupted only by Fourth Cliff, from whose waste a portion of the material of the levee seems to have been selected.

It is not impossible that the river once found its outlet between the Third and Fourth Cliffs, as most of the people living in the neighborhood conceive. Instances are numerous where streams have been turned aside, and sometimes cut off from the sea, by the advance of shingle.

Shingle-levees appear to me to be worthy of careful study, because they are the best natural measures of the power of storm-waves, and I have made the dimensions of this one at Scituate a special subject, in order to ascertain to what height the *dikes*, required farther down the beach, must be carried in order to prevent the overflows that now frequently occur.

The portion of the levee which lies between Third and Fourth Cliffs is about four thousand three hundred feet in length, with a general elevation of sixteen feet above the plane of high water, and a base of two hundred feet. It is composed of round and oval stones, those near the water-line of the seaward side being the largest, and those upon the summit the most flattened. Paving-stones are gathered from the lower portions of the outside, but upon the summit the average size may be stated at three and a half inches maximum diameter, and one inch thick in the middle.

The crest of the levee appears to the eye perfectly horizontal, and but slightly curved back from a straight line. The table of levelings given below, however, shows that there are depressions at either extremity, and that it is only the highest portion that is very near the horizontal for any considerable distance.

Longitudinal section of shingle-levee.

Datum=High water of the sea.

Distance in meters.	Height above mean high water of sea.	Distance in meters.	Height above mean high water of sea.	Distance in meters.	Height above mean high water of sea.
0	14. 32*	5. 40	16. 15	10. 20	13. 71
60	12. 83	6. 00	16. 15	10. 80	13. 04
1. 20	15. 45	6. 60	15. 65	11. 40	13. 41
1. 80	17. 00	7. 20	15. 30	12. 00	12. 71
2. 40	16. 40	7. 80	14. 73	12. 60	11. 01
3. 00	16. 70	8. 40	15. 03	13. 20	9. 21†
3. 60	16. 77	9. 00	14. 29	13. 20	13. 21‡
4. 20	17. 10	9. 60	13. 71	13. 40	22. 41§
4. 80	15. 95				

* Foot of Fourth Cliff. † On levee. ‡ On bluff. § On Third Cliff.

Within the memory of persons now living in Scituate, the sea has once (during the Minot's gale) leaped over this levee, and the sea-water had several times been seen oozing through, but to no extent that could be injurious in ordinary winter storms.

The height of this levee is greater than is usual among such formations, and its stones are larger. The maximum height given in our table is seventeen feet above mean high water of the sea. Redman estimates the ordinary height of these formations in Great Britain at six to ten feet.

The two slopes of our levee, as given by our cross-sections, are very unlike in some respects; that toward the sea presents a series of berms, miniatures of the great levee, thrown up by subsequent storms,[*] while the leeward slope (toward the river) is a smooth hollow curve. (Figs. 5, 6, and 7.)

In the following tables I give the elements for profiles of ten cross-sections of our shingle-levee, and a mean section from the higher and less disturbed portion. (See Figs. 5, 6, 7, and 8.)

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[*] Redman and Coode, in their papers read before the Institute Civil Engineers, used the word "fulls" for these windrows or berms which mark the action of the recent storms.

Sections of shingle-levee.

	SECTION I.		SECTION II.		SECTION III.	
	120 meters.		240 meters.		360 meters.	
	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.
Fore shore	65. 6	0. 13	....	....	78. 7	0. 21
	59. 0	2. 33	....	....	62. 3	4. 51
	52. 5	4. 63	....	....	52. 5	6. 41
	45. 9	4. 93	65. 6	1. 60	45. 9	7. 31
	39. 4	6. 03	52. 5	5. 20	39. 4	9. 11
	32. 8	6. 43	36. 0	7. 80	29. 5	10. 17
	19. 7	9. 05	29. 5	9. 50	22. 9	13. 27
	9. 8	13. 45	19. 7	8. 83	16. 4	15. 17
	6. 6	14. 15	6. 6	13. 80	6. 6	15. 57
Crest	0	15. 45	0	16. 40	0	16. 77
Back shore	6. 6	14. 95	13. 1	14. 20	3. 3	16. 47
	19. 7	12. 85	26. 2	9. 60	16. 4	13. 87
	32. 8	9. 82	39. 4	6. 12	26. 2	10. 04
	45. 9	7. 72	65. 6	2. 80	36. 0	6. 70
	65. 6	6. 42	82. 0	1. 40	59. 0	3. 90
	98. 4	4. 52	98. 4	0. 70	68. 9	4. 00
	131. 2	2. 72	111. 5	—1. 30	85. 3	3. 00
	144. 3	1. 92	....	....	104. 9	2. 30
	154. 2	1. 12	....	....	118. 0	—0. 10
	164. 0	—1. 28	....	....	134. 5	—1. 42

NOTE.—The datum plane is mean high water of the sea. The distances in meters are measured along the crest from Fourth Cliff.

Sections of shingle-levee.

	SECTION IV.		SECTION V.		SECTION VI.	
	480 meters.		600 meters.		720 meters.	
	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.
Fore shore	88. 6	—1. 56	....	....	....	....
	72. 2	1. 14	98. 4	—2. 50	....	....
	62. 3	3. 14	75. 4	0. 20	88. 6	—2. 80
	55. 8	4. 84	65. 6	2. 50	55. 8	2. 90
	39. 4	7. 04	55. 8	5. 10	49. 2	4. 50
	32. 8	8. 74	49. 2	5. 10	32. 8	7. 30
	29. 5	9. 82	36. 0	7. 40	22. 9	8. 00
	22. 9	12. 45	29. 5	7. 90	19. 7	9. 07
	13. 1	12. 85	19. 7	9. 38	9. 8	10. 90
	6. 6	13. 95	9. 8	11. 90	6. 6	12. 00
Crest	0	15. 95	0	16. 15	0	15. 30
Back shore	9. 8	14. 65	9. 8	15. 65	9. 8	14. 30
	19. 7	12. 55	16. 4	14. 55	26. 2	10. 60
	42. 6	6. 63	26. 2	11. 55	42. 6	6. 40
	75. 4	3. 86	32. 8	9. 12	75. 4	2. 40
	108. 2	2. 76	49. 2	4. 86	108. 2	1. 50
	141. 0	—0. 24	65. 6	2. 66	141. 0	0. 70
	157. 4	—0. 74	82. 0	1. 76	173. 8	0. 70
	164. 0	—0. 04	114. 8	1. 26	....	....
	183. 7	—0. 14	147. 6	0. 56	....	....

Sections of shingle-levee.

	SECTION VII.		SECTION VIII.		SECTION IX.		SECTION X.	
	840 meters.		960 meters.		1,080 meters.		1,200 meters.	
	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.	Distance in feet.	Height above mean high water of sea, in feet.
	....	....	....	....	....	....	114. 8	—5. 00
	....	....	....	....	....	....	88. 6	—2. 00
	98. 4	—3. 00	....	....	124. 6	—4. 56	65. 6	1. 20
	82. 0	—1. 10	....	....	108. 2	—3. 66	59. 0	2. 90
	65. 6	2. 40	12. 14	—4. 50	75. 4	—0. 16	55. 8	4. 10
	59. 0	4. 83	88. 6	—1. 20	68. 9	1. 24	49. 2	4. 40
	49. 2	5. 00	68. 9	1. 20	55. 8	4. 72	42. 6	5. 40
	42. 6	6. 70	55. 8	4. 50	39. 4	6. 14	39. 4	6. 70
	32. 8	6. 91	42. 6	6. 40	22. 9	7. 14	26. 2	7. 01
	22. 9	8. 80	29. 5	6. 64	13. 1	10. 34	16. 4	8. 50
	9. 8	11. 60	6. 6	12. 20	9. 8	10. 94	6. 6	10. 70
Crest	0	15. 03	0.	13. 71	0	13. 04	0	12. 71
	6. 6	13. 70	9. 8	13. 30	6. 6	12. 80	6. 6	12. 30
	16. 4	11. 10	29. 5	9. 60	16. 4	11. 40	16. 4	11. 20
	32. 8	8. 11	42. 6	7. 50	29. 5	9. 11	49. 2	7. 40
	49. 2	5. 00	75. 4	4. 87	55. 8	5. 74	82. 0	2. 88
	72. 1	2. 30	108. 2	2. 90	72. 2	3. 94	114. 8	1. 20
	98. 4	1. 70	141. 0	1. 00	104. 9	2. 04	147. 6	0. 50
	127. 9	0. 60	173. 8	0. 70	121. 4	1. 64	180. 4	—0. 70
	164. 0	0. 60	....	....	154. 2	1. 34	....	....
	....	....	....	....	186. 9	0. 44	....	....

Mean of Sections I, II, III, IV, V, VI. (Fig. 8.)

	Distance.	Height above mean high water of sea, in feet.	Slope.
Fore shore................	90 feet........................	—1. 82	0. 133
	80 feet........................	—0. 49	0. 199
	70 feet........................	1. 50	0. 107
	60 feet........................	2. 57	0. 279
	50 feet........................	5. 36	0. 162
	40 feet........................	6. 98	0. 163
	30 feet........................	8. 61	0. 187
	20 feet........................	10. 48	0. 243
	10 feet........................	12. 91	0. 309
Crest	0 feet........................	16. 00	0. 000
Back shore................	10 feet........................	14. 84	0. 116
	20 feet........................	12. 50	0. 234
	30 feet........................	9. 50	0. 292
	40 feet........................	7. 12	0. 246
	50 feet........................	5. 60	0. 152
	60 feet........................	4. 52	0. 108
	70 feet........................	3. 72	0. 080
	80 feet........................	3. 06	0. 066
	90 feet........................	2. 66	0. 040
	100 feet........................	2. 27	0. 039
	110 feet........................	1. 60	0. 067
	120 feet........................	1. 44	0. 016
	130 feet........................	0. 89	0. 055
	140 feet........................	0. 87	0. 002
	150 feet........................	0. 54	0. 033
	160 feet........................	0 01	0. 053

For the height of the above mean section Caland's dike formula would give a fore slope of 4 : 1; but, as the table shows, the inclination varies from a maximum of 3 : 1 to a mean of 5 : 1 for our natural dike. In the grand dike of Petten, (North Holland,) which is still in course of construction, the mean slope is 9 : 1; but I find from my notes made upon the spot in 1868 that for the storm-belt, covered with basalt blocks, the slopes are 5 : 1 and 3 : 1; so that the work of several centuries begins to approach the economy of nature.

The leeward slope of our levee, for different sections, is very nearly the same from point to point except near the base, where it is affected by different elevations of the river-bed upon which it lies. It is probably the curve of least resistance for the material employed. It sometimes approximates quite closely the cycloid, and it always has an aproning to protect the base. If it were steeper, the fall of overflowing water would excavate the marsh at the foot and endanger the whole structure; if it were less inclined, there would not only be a waste of material, but, in the event of a rapid succession of overleaping seas, the accumulated waters might react and burst through the crest.

My assistant, Mr. H. L. Marindin, has recently examined the levee near Chelsea, Massachusetts, the southern portion of which is more exposed to the sea, and therefore the highest, reaching an extreme elevation of 14.13 feet above mean high water. The fore slope of this portion has an average inclination of 5 : 1, and an extreme near the crest of 2¾ : 1. The exposure is only to the south-easterly quadrant, and the shallow flats, which extend a long way to the seaward, break the force of the sea. The longitudinal profile of this levee shows a decline of height as the observer moves to the northward, reducing the angle of exposure, and falling under the shelter of Nahant. This levee has a rear slope of 3 : 1 above the apron.

Below Fourth Cliff the shingle-levee continues for a considerable distance, but gradually loses its distinctive character, and merges with the sands, which seem to have preceded all other material in the march southward. In the year 1855 the communities about the North River attempted to cut a new outlet in this portion of the beach, using at first hand-labor, but ultimately employing a dredging-machine. The bottom was removed to a depth of six feet below the marsh level, but not to the low water of the sea. Contrary to expectation, the water, instead of flowing seaward, rushed in toward the river, Fourth Cliff Bay being at times, as we find from our observations, below the high water of the sea. The influx was very strong, but seemed quite powerless to enlarge or deepen the trench through the firm and unctuous soil of the marsh; to use the expression of the workmen, "*the stream wouldn't gull.*" Heavy weather came on soon after the work of the dredging-machine ceased, and the waves drove in masses of sand and stones, which soon choked up the pass. In course of time a shingle-levee formed across the inlet, and rose to the height of 10 feet above the high-water plane of the sea. I give a section of this new formation, in which no decided berms appear.

Cross-section of new levee.

FORE SLOPE.		REAR SLOPE.	
Distance from crest, in feet.	Elevation above mean high water of sea, in feet.	Distance from crest, in feet.	Elevation above mean high water of sea, in feet.
137	— 7.6	0	10.9†
102	— 4.6*	20	7.3
72	— 1.8	33	5.3
49	1.5	59	3.5
39	4.0	125	1.8
33	5.2	192	— 0.3
23	6.9	256	— 1.7‡
13	10.5	....	....
6	10.7	....	....

* Half tide or mean lever of sea. † Crest. ‡ High-water plane of river.

NOTE.—The average fore slope, above the plane of high water, is 5 : 1, while the greatest inclination, (near the crest,) is 2¾ : 1.

I glean one very curious fact from those employed in opening this channel, viz, the original bank of shingle was found to extend downward only to the surface of the marsh, which was not sensibly depressed beneath its weight. I infer that, as Fourth Cliff wears away, the whole beach falls back, and the present banks of sand and shingle are really superimposed upon ancient meadow lands or river channels. The marshes are not floating bogs like the *koogs* of Denmark, or liable to slump down after inclosure, like the *polders* of Holland. The newly formed levee, across the mouth of the artificial outlet, exerts a pressure of over twelve hundred pounds to the square foot upon the marsh beneath its crest, and the weight of the original bank, as far as I can judge, was over seventeen hundred pounds to the square foot under the crest. I have allowed in these estimates 25 per cent. for voids. Old rubble breakwaters that have been shaken down by the waves to a state of repose occupy still a space 25 to 30 per cent. greater than the rock *in situ.*

Some shrinkage will no doubt take place after drainage is effected, but this will not, I think, exceed 10 to 12 per cent. If the *water-table* is dropped four feet I shall expect the marsh surface to sink about six inches.

Sand-beach.—Further down the Scituate Beach the stones gradually give place to sand, and the shore no longer reflects the action of the sea alone, but is diversified by dunes blown up by the winds. There are occasional points where traces of overflow appear, and I give the section of one of the slue-ways formed by the Minot's gale, and traversed by the sea at least once a year since that memorable storm:

Section from upland to ocean, crossing North River at Slant Spar, (Fig. 10.)

Distance in feet.	Elevation in feet.	Distance in feet.	Elevation in feet.
0	4.34	478	—3.6
36	1.72	493	—2.9
85	0.93	508	—2.9
125	1.44	523	—2.9
141	1.19	538	—2.9
243	0 37	554	—0.92
262	0.72	590	1.08
328	—0.92	656	2.89
343	—2.9	934	5.05
358	—3.0	1,000	5.50
373	—4.5	1,066	6.78
388	—4.9	1,197	8.76*
403	—4.2	1,262	6.68
418	—4.2	1,331	4.94
433	—4.2	1,387	0.95
448	—3.9	1,426	0.71
463	—3.9	1,5 5	—4.00

NOTE.—Datum = High-water plane of river, June 23, 1870 = 1.70 feet below mean high water of sea.

* = 7.06 above mean high water of sea.

The maximum height of this slue-way is seven feet; this may be regarded as the measure for annual overflow, especially as I find the same measure on other parts of the New England coast.

I have given in Fig. 10 a profile, plotted from the preceding table, because it illustrates so well the double action in overflow, the violent dash against the seaward face, and the flowing down on the opposite slope. On sandy shores, a mound thrown up by the sea can nearly always be distinguished from one due to the wind; in the former the steeper slope is *seawards*, in the latter *leeward*, so that an overflow reverses the order of the slopes found in a dune. Sections which I have since run across the "Haulover," at the head of Nantucket Harbor, and those through the slues of Cotamy Beach, at the head of Edgartown Harbor, give the same general curve with the same maximum elevation *within six inches.* In running water (in the bed of a river for instance) the sands take the form of flat dunes, which correspond in the order of their slopes with those on land.

General rise.—The *mean-level* rises during storms from seaward, and this must always be taken into account in projects for dikes and dams. This *general rise* can best be measured by observing the height of the water's surface in sheltered coves and harbors. Major Graham's report on Cape Cod Harbor shows, from tidal observations between 1833 and 1835, that a twenty-four hours' gale from the southeast (*i. e.*, directly into Massachusetts Bay) causes a general rise of 3.33 feet. The coping of the United States dry-dock at Charlestown was designed to be above the highest tide, and was placed 4.69 feet above mean high water. The sea has actually risen 0.4 above the top of this coping once during the past twenty years. If we grant that the storm-rise is affected by the configuration of a harbor or bay in no greater degree than the ordinary tide, we must apply a correction to the dry-dock rise of nearly 10 per cent. in order to reduce it to its proper proportion for the outside coast. We have then four and a half feet for the *general rise* during violent storms. I do not think it necessary to go back more than twenty years in estimating the height to which the sea is likely to rise, because there is no economy in providing for contingencies which do not present themselves more than once in a life-time. In Holland, where the lives of thousands depend upon the security of the dikes, the works are only provided for ten feet general rise, although the tradition of the Cimbrian flood is over forty, and the Deluge greater yet.

Dean's History mentions that the sea has been known to flow over the isthmus which divides Scituate Harbor from the North River, and I am informed that during the Minot's gale the rush over this place was so great as to sweep away fences, &c. I have not time to run a line of levels over this isthmus, which I regret, because I think it would have given an excellent measure for "*general rise*." The overflow in the Minot's gale, to which I have just referred, injured the lands to such an extent that it was not until the third season after that the English grass recovered its former luxuriance.

To recapitulate: The heights to which the sea has run upon the outside shore above mean high water of the sea are—

In the heaviest gale observed, (Minot's)	17 feet.
In the heaviest gale of the year	13 "
In ordinary winter storms	7 "

The beach should be protected against a fourteen feet run of the sea. We have found between the Fourth Cliff and the South River junction only five slues which fall below this standard height, and these we have sectioned. The point of the beach near the North River is generally low for twelve hundred feet, but will afford, I think, no source of trouble for many years.

The interior dams must be at least three and a half feet, but need not (if perfectly sheltered) exceed four and a half feet above the mean high-water plane of the sea to escape overflow from the "*general rise*" during storms. The bench of our survey is situated on the right bank of the river, nearly opposite Slanting Spar. It is within a circle cut upon the highest point of a boulder, which boulder may be distinguished from other rocks by its having an iron ring-bolt on one side. This bench is 1.23 feet above *mean high water of the sea*, (as computed.)

Mouth of river.—During the last century the river mouth has been forced to the southward by the advance of the beach a distance of nearly one mile, and, since our survey of 1858, about one thousand feet. A beach of small shingle now stretches from the coast south of the embouchure, and overlaps the beach of which I have been speaking, so that the river makes a sharp turn just before issuing upon the sea.

Between the mouth of the river and White's Ferry the stream has been injured by overflows from the sea, which have not only rendered the channel more shallow but made it narrower than formerly, the material of the beach being much of it too heavy for the ebb-current to remove, and the opposite bank of the stream too firm to yield in due proportion.

The shoalest place in the river is in the vicinity of the slue-way ot which we have given the section in Fig. 10. It is encumbered with banks, and the average depth of a pathway one hundred feet wide, along the line of greatest depression, is only five feet in ordinary high water. Tradition says that nearly a century ago the mouth of the river was at this point, and that since the river moved on there have remained here impediments to navigation. However this may be, the Minot's gale reopened a track over the beach, and poured into the stream a mass of gravel and shingle that completed the ruin of the river as far as navigation is concerned. We have made a close survey of this portion of the stream, and deposited a chart of it at the office, bearing the names of the observers.

Tides.—Dean's History, as we have seen, gives "three to five feet" as the rise and fall of the tide at North River Bridge forty years ago, and I am inclined to accept the statement, not only because the author is reputed to be careful in such matters, but also because the recollections of Captain Tolman and other persons in this very intelligent neighborhood confirm it. In the present obstructed condition of the rivers, the range of tide at North River Bridge varies from 0.8 to 1.5 feet, and the range does not now exceed these figures at any point above White's Ferry, near which the modern overflows have occurred. The obstructions act as weirs, over which only the upper portion of the tide flows. The highest place in the river bed along the thread of the channel is 1.60 feet below the mean level of the sea, and upon this weir the tide does not rise to the high-water level of the ocean, because of the rush into the reservoir beyond, which does not get filled in the short time allowed.

The following table exhibits the times and heights of a low neap tide:

Tides of North River.

Station.	High water, interval after moon's transit.		Range of tide in feet.
	h.	*m.*	
Cape Cod Bay	11	10	*7.7
Station 1st	11	15	4.7
Station 2d	11	30	3.7
Station 3d	11	40	1.7
Roger's Wharf	11	44	0.8
Little's Bridge	13	42	†0.5
Union Bridge	13	59	0.6
North River Bridge	14	30	0.8

* Spring range = 10.58. † Spring range = 1.1.

The obstructions in the lower reach of the river do not protect the marshes from an inundation on the occasion of a great *general rise* outside, because, after the river mounts two or three feet above ordinary high water, its section becomes very ample all the way from the sea. But the obstructions play their part in preventing the prompt relief from inundation, since, with the subsidence of the *general rise* outside, the sections at the obstructions return to their ordinary dimensions and the outlet is choked. What is true of inundations due to "general rise," is also, in a measure, true of every spring tide. The high-water volumes flow easily up the river into the Fourth Cliff Bay, but are so delayed that when they would return to the sea they find that the fall of the tide has left but a contracted section in the lower reach of the stream, and, although this becomes the scene of a torrent during the low stages of the outside tide, the relief is not afforded for several days. It is especially at the season of hay-cutting on these meadows that the prolonged inundations become injurious; and Captain Tolman informs me that an increase in their durations has been observed and much commented upon by persons whose memories go back to better times.

Of course the order of the tidal currents is very much affected by the tendency of the obstructions to limit the supply of tide-water in the reservoirs during the rise, and pond it back during the fall. The flood current, although it does not begin to run in over the shoals until it lacks but about two hours and a half of high water, continues about one hour and a half after the tide has begun to sink. The ebb current continues about eight hours, and runs most rapidly about the time it is low water in the sea. You will perceive that the flood and ebb, the one pouring in at high water, the other struggling out at low water, cannot be properly compared by their durations alone, but their volumes must be considered since the sections are unlike. Here is a case where "Professor Peirce's criterion" is not applicable for obvious reasons, and it becomes necessary to compute the fresh water supply from actual gauging. This computation is given in the following table from observations over a short reach just below the shoals:

Mean height of surface.	Time, 23d June, 1870.		Mean section.	Mean velocity, per second, in feet.	Volume, per second, in cubic feet.	Period, in seconds.	Volume, in cubic feet.
	h. m.	*h. m.*					
0. 9	5 34	6 00	705	0. 4	282	1, 560	439, 920*
1. 3	6 00	7 00	792	1. 6	1, 267	3, 600	4, 561, 200†
1. 7	7 00	8 00	879	2. 6	2, 285	3, 600	8, 226, 000
1. 6	8 00	9 00	857	1. 6	1, 371	3, 600	4, 935, 600
1. 2	9 00	9 15	770	0. 2	154	900	138, 600
Inflow							18, 301, 320
0. 9	9 15	10 00	705	0. 8	564	2, 700	1, 522, 800
0. 6	10 00	11 00	640	2. 4	1, 536	3, 600	5, 552, 960
0. 3	11 00	12 00	575	3. 3	1, 897	3, 600	6, 829, 200
0. 2	12 00	13 00	553	3. 3	1, 825	3, 600	6, 570, 000
0. 1	13 00	14 00	532	3. 1	1, 649	3, 600	5, 936, 400
0. 05	14 00	15 00	522	2. 9	1, 514	3, 600	5, 450, 400
0. 0	15 00	16 00	510	2. 9	1, 479	3, 600	5, 324, 400
0. 10	16 00	17 00	532	2. 2	1, 170	3, 600	4, 212, 000
0. 5	17 00	17 29	618	0. 6	371	1, 740	645, 540
Outflow							42, 043, 700

* Mean L. W. section 510; mean H. W. section 879. † The height of surface is referred to low water, (4. 6 below "Primary Bench.")

Effect of a dam.—From the above table the river discharge may be computed to be 11,871,190 cubic feet during six hours, and this quantity includes any reservation from the preceding higher tides. Now the area of the river surface above the gauging place, and below the North River Dam, is 32,920,470 square feet, exclusive of tributaries and creeks. If, upon the day of gauging, a dam had been thrown across the stream, the average rise of the river behind it would have been 0.36 of a foot in six hours. As the area of the river surface would be reduced by drainage, the average rise, under otherwise similar circumstances, would be slightly augmented.

The figures I have given are true for the period of my observations, but of course vary with the rain-fall at different seasons. My acquaintance with the river is too short to permit me even to conjecture upon what date in the spring the river becomes drainable. On September 29, just before the beginning of the rains, after the long drought of the past season, my aid, Mr. F. H. North, gauged the river again at Little's Bridge, at the head of Fourth Cliff Bay, and found the flood and ebb currents of nearly equal duration, and the density of the water as high as 1.017 on the last of the ebb. In effect the stream had become an arm of the sea, without any perceptible rise due to fresh water.

During the coming winter and spring opportunities will be offered for examining the conditions of the river under the circumstances most opposed to drainage, and I suggest to the marsh owners an occasional repetition of some of the observations I have detailed in this report, that the whole scheme may be reduced to figures, and not a dollar spent that can be saved, or saved at the expense of success.

The removal of the shoals from the lower reach of the river is the obvious remedy for all difficulties of discharge, but the depth to which the dredging should be carried ought not to be decided upon before observations in the wet season are made. Deepening to the level of mean low water of the sea will be the utmost that can become necessary, and I hope that something even may be saved of this.

In addition to the observations which form the basis of the tide table given above, we have half-hourly records of the rise and fall at stations simultaneously occupied, so that we can follow all the tidal phases from the sea to the North River Dam. I am obliged to omit, however, these details, because they are too voluminous for this report, and would require long explanations, but I shall venture to comment upon them briefly, to show their practical bearing upon the engineer's project.

I conceive that the engineer, in deciding upon the dimensions of his sluice-gates, may find it necessary to compute the variations of the slope, and a study of the progress of the tidal phases will be his best resource.* A gate closed upon a stream produces an effect like that of the rising tide at slack water, and the rise due to the closure is propagated at the same rate (essentially) as that of the tide. In a similar way, the depression caused by the opening of a sluice-gate falls back like the tide. With the North River at the level we found it, the rise on the closure and the fall on the opening of a sluice-gate at White's Ferry would affect Fourth Cliff Bay in about one hour, the neighborhood of Little's Bridge in one hour and fifty-eight minutes, and the neighborhood of North River Dam in two hours and forty-six minutes. The duration of rise or fall would everywhere be equal to the time of closure or opening, so that at North River Bridge the water would sink for two hours and forty-six minutes after the gates were closed, or rise two hours and forty-six minutes after the same were opened. Fourth Cliff Bay performs the function of a reservoir, and the sluice-gates should be placed as short a distance below as other circumstances will admit.

GENERAL CONCLUSIONS RELATIVE TO THE PROJECTS OF RECLAMATION.

First. The marshes of Green Harbor River may be drained by the construction of a sluice-dam at Turkey Point without unusual precautions or expense, but not without injury to the present facilities for navigation below said point.

Second. The North River marshes can be drained by constructing a sluice-dam at White's Ferry, provided the present obstructions below are removed by dredging; and provided, also, that dikes are carried across the "slue-ways" of the beach, to the height of fourteen feet above mean high water of the sea.

Third. The dams, to escape overflows from the "general rise" during storms, must be carried at least four and a half feet above mean high water of the sea.

Fourth. The marshes after drainage will not sink or shrink more than twelve per cent. of their elevation above the water-table.

SHORES OF NAHANT.

At the request of Professor Agassiz, who became interested in our studies of the littoral cordon, I visited the shingle levees of Nahant, and subsequently directed my assistants to run levels over them. I give in full Mr. Marindin's interesting notes on Pond Beach, &c.:

"As the observer traverses the levee, he finds that the material varies from well rounded shingle to gravel, and further on to angular stones which approach rectangular forms, in the neighborhood of Bayley's Hill, from whose ledges the angular blocks have evidently been broken off.

"At section 1 well-rounded shingles are found, varying from 5 by 4 inches down to pebbles ½ by ½ inch; on this section I have measured the shingle on the fore-shore at every foot of distance from the crest; the measurements show the larger shingle about five feet from the crest and gradually diminishing in size to the water's edge, where it may be called gravel. I have taken for measurement the mean-sized stone at the spaces of every foot from the crest.

"At section 2 the same material is found. Here, however, the levee attains its maximum height, viz, 12.73 feet above mean high water of the sea. From section 2 the material changes, till at section 3 (five hundred feet to the westward of section 1) the size and quantity of shingle has been reduced, and a large mixture of gravel and sand substituted. The largest shingle in this section is found between thirty-five and forty feet from the crest on the fore slope. Here is also seen a line of large boulders, five feet from the crest, which appear to have been placed there by hand, as they are well aligned, forming a low wall parallel to the crest. On this fore shore I have measured the material also for every foot of distance from the crest; these I give below.

"From section 3 to within forty feet of section 4, the material has the aspect of quarry chips; for a belt of twenty-five feet in front of, and parallel with the crest, the interstices are filled with sand and gravel, and the space below the belt is almost clear gravel to the water line. The rear slope is almost wholly of sand. From the limits just mentioned (five hundred and sixty feet west of section 1) to section 4 a change occurs, two irregular blocks averaging 4 by 4 by 2 inches on both the fore and rear slopes; a few larger angular blocks are scattered around, mainly along the crest, where they appear to have been laid by hand-labor; one of these blocks measured 2 by 2 by ½ feet cube. The crest of the levee, as far as section 4 and beyond, appears very even, the irregularities being due to the different heights of the blocks composing it. Between sections 4 and 5 the beach, so to speak, ends very abruptly at a point about twenty feet from section 4, and six hundred and twenty feet west of cross-section 1.* Here we find large angular blocks on the fore slope, and smaller blocks about the size and shape of paving-stones on the rear slope; this extends as far as section 5, where the material increases in size both on the fore slope and rear slope to section 6 and to the foot of Bayley's Hill, where the levee ends.

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*An indispensable computation, if freshets are to be provided for.

"For a length of two hundred feet from the foot of Bayley's Hill, the profile of the crest of the levee shows a series of pretty uniform depressions and elevations. The direction of these depressions or slues is not normal to the crest, but approaches parallelism with the line of greatest exposure.

"The levee, as near as I could judge, runs in a northerly and southerly direction at this point, while the depressions seem to lie nearly southeast and northwest.

"I have measured two of the largest blocks found on the levee, one on the crest near cross-section 5, at a height of 6.8 feet above mean high water of the sea. From a rough calculation this block contains somewhat over three thousand cubic inches. The other was half way up the fore slope, between sections 4 and 5, about five feet above mean high water; it contains five thousand cubic inches.

"A bench-mark was established on the apex of a boulder inside of the stone-wall in rear of cross-section No. 3. The boulder is conical, and has the letters C. S. cut into it on the side facing the sea. A few small trees are scattered around. This B. M. is 7.467 feet above mean high water of the sea.

"I give in section No. 7 a transverse section of a shingle-mound between Bass Point and Bayley's Hill. This mound was thrown up by the waves between two rocky ledges which extend some distance into the sea; these limit the length of the levee to nearly one hundred and fifty feet. The height increases from either end toward the center, where the measurements of the cross-section give a height of 16.57 feet above mean high water of the sea. The shingle is similar in size and shape to that found at section No. 1 on Pond Beach. No large irregular blocks are seen on this levee, although the adjoining shores are rocky, and ledges extend into the sea at different points."

In a note received as this report goes to press, Professor Agassiz says: "The evidence of the very recent origin of a portion of the shingle-levee at Nahant is as plain and direct as you can wish it; for the larger fragments of rock and smaller materials of which it consists, rest upon a stone-wall built to support a road leading to Bass Point. This wall was not built earlier than 1817. That part of the levee which covers the stone-wall and road leans westwardly upon Bass Point, and eastwardly merges with the levee that extends all along the cove."

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* The minimum height of the levee is at a point 817 feet west of cross-section 1, 6.47 feet above mean high water; the material is angular blocks.

Sections of levees on Pond Beach, Nahant.

CROSS-SECTION NO. 1.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Fore shore.	60	2. 77	0. 15	Water comes up to this.
	50	4. 27	0. 17	Well-rounded shingle, varying from 5 by 2 inches down to gravel.
	40	5. 92	0. 10	
	30	6. 96	0. 30	
	20	9. 97	0. 70	
	10	10. 61	0. 13	
Crest..	0	11. 94	0. 00	
Back shore.	10	11. 02	0. 90	
	20	8. 92	0. 21	
	30	6. 44	0. 25	
	40	5. 14	0. 13	Road passes between 40 and 60.
	60	4. 00	0. 05	
	70	2. 86	0. 11	
	80	1. 55	0. 12	
	90	—0. 14	0. 17	Water surface in pond.

CROSS-SECTION NO. 2—200 FEET WEST OF SECTION 1.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
Fore shore.	63	—0. 51	0. 19	Well-rounded shingles, same as at section 1.
	40	3. 87	0. 12	
	20	6. 52	0. 25	
	10	9. 03	0. 37	
Crest..	0	12. 73	0. 00	
Back shore.	10	10. 98	0. 17	
	20	8. 68	0. 25	
	30	6. 88	0. 18	
	40	5. 88	0. 10	
	50	4. 18	0. 17	
	60	3. 26	0. 09	

CROSS-SECTION NO. 3.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
Fore shore.	67	0. 39	0. 27	Fore shore of shingle.
	60	2. 36	0. 12	
	50	3. 58	0. 19	
	40	5. 50	0. 01	
	30	5. 65	0. 09	
	20	6. 60	0. 02	
	10	6. 81	0. 21	
Crest..	0	8. 89	0. 00	
Back shore.	20	8. 70	0. 01	Back shore of sand and gravel.
	40	7. 95	0. 04	
	60	7. 12	0. 04	
	74	6. 85	0. 02	

CROSS-SECTION NO. 4—600 FEET WEST OF SECTION 1

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Fore shore.	60	—1. 48	0. 09	
	40	0. 42	0. 15	
	30	1. 93	0. 10	
	20	2. 89	0. 25	
	15	4. 09	0. 25	
	10	5. 34	0. 36	
	05	7. 13	0. 07	
Crest..	0	7. 52	0. 00	
Back shore.	10	6. 81	0. 07	
	20	6. 41	0. 04	
	27	5. 58	0. 12	

CROSS-SECTION NO. 5.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
Fore shore.	50	—1. 48	0. 12	Large angular blocks, varying from 4 inches to 2-feet cubes.
	40	—0. 33	0. 08	
	30	0. 46	0. 19	
	20	2. 41	0. 21	
	10	4. 53	0. 23	
Crest..	0	6. 83	0. 00	
Back shore.	10	6. 51	0. 03	
	20	6. 03	0. 05	
	30	5. 11	0. 10	
	37	3. 73	0. 20	

CROSS-SECTION NO. 6—926 FEET WEST.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
Fore shore.	50	—1. 97	0. 11	Large irregular angular blocks, varying in size from 1-foot to 2-feet cubes.
	40	—0. 87	0. 26	
	30	1. 70	0. 27	
	20	4. 46	0. 27	
	10	7. 26	0. 28	
Crest..	0	10. 05	0. 00	
Back shore.	05	8. 11	0. 38	
	10	7. 23	0. 18	
	15	6. 73	0. 10	
	20	7. 03	0. 06	
	25	5. 93	0. 22	
	30	5. 03	0. 18	

Sections of levees on Pond Beach, Nahant—Continued.

MOUND NEAR BASS POINT, SECTION NO. 7.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Fore shore.	65	—1.48	0.19	Well-rounded shingle, varying from 5 by 2 inches down to gravel.
	50	1.47	0.39	
	44	3.87	0.14	
	37	4.89	0.71	
	34	6.98	0.31	
	29	8.50	0.33	
	17	8.87	0.50	
	08	12.11	0.43	
Crest..	0	16.57	0.00	
Back shore.	06	15.56	0.17	
	12	13.81	0.28	
	18	11.86	0.33	
	22	10.79	0.25	

MEAN OF SECTIONS NOS. 1 AND 2.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
Fore shore.	60	1.13	0.18	Water comes up to this.
	50	2.97	0.19	Well-rounded shingle, varying from 5 by 2 inches down to gravel.
	40	4.89	0.12	
	30	6.07	0.22	
	20	8.25	0.16	
	10	9.82	0.25	
Crest..	0	12.33	0.00	
Back shore.	10	11.00	0.13	
	20	8.80	0.22	
	30	6.66	0.22	
	40	5.51	0.11	
	50	4.37	0.11	
	60	3.63	0.07	
	70	2.86	0.07	
	80	1.55	0.13	
	90	—0.14	0.17	Water surface in pond.

LONGITUDINAL SECTION FROM SECTION 1 TO BAYLEY'S HILL.

	Distance.	Height above mean high water of sea.	Slope.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Along the crest of the levee.	0	11.94	......	Cross-section No. 1.
	100	12.68		
	200	12.73	......	Cross-section No. 2.
	300	12.72	......	Rounded shingle.
	400	12.56		
	500	8.89	......	Cross-section No. 3.
	600	7.52	......	Cross-section No. 4.
	700	7.57		
	800	7.82		
	811	8.32	......	Large angular blocks.
	817	6.47		
	821	7.69		
	837	6.83		
	838	6.83	......	Cross-section No. 5.
	848	8.54		
	857	7.12		
	862	8.17	......	Large angular blocks.
	874	8.72		
	887	7.38		
	896	8.96		
	905	10.00		
	914	8.42		
	926	10.05	......	Cross-section No. 6.
	934	10.26		
	942	7.97		
	952	10.12		
	966	10.69		
	984	11.09		
	1000	9.59		
	1006	9.69	......	Foot of bluff at Bayley's Hill.
	1012	10.69		

The reader is referred to the *Journal of the Franklin Institute*, Vol. LXII, for a valuable paper on the manner of determining the proper size of sluice-gates, which has been written since my report was completed, by Clemens Herschel, C. E., upon whom the constructive engineering of the proposed reclamations will devolve.

In the prosecution of my physical surveys in this section during the past season, I have been assisted by volunteers from the Massachusetts Institute of Technology. To Mr. Hoyt, (instructor,) and to Messrs. Pike, Stone, Howland, and Curtis, (students,) whose admirable training at the Institute fitted them for immediate usefulness, I am much indebted for the accuracy of my observations, and for the rapidity with which my work was performed.

HENRY MITCHELL,
Chief in Physical Hydrography, U. S. C. S.

Professor BENJAMIN PEIRCE,
Superintendent U. S. C. S.

No 1.

Fig: 1:

Scale, $\frac{1}{80.000}$

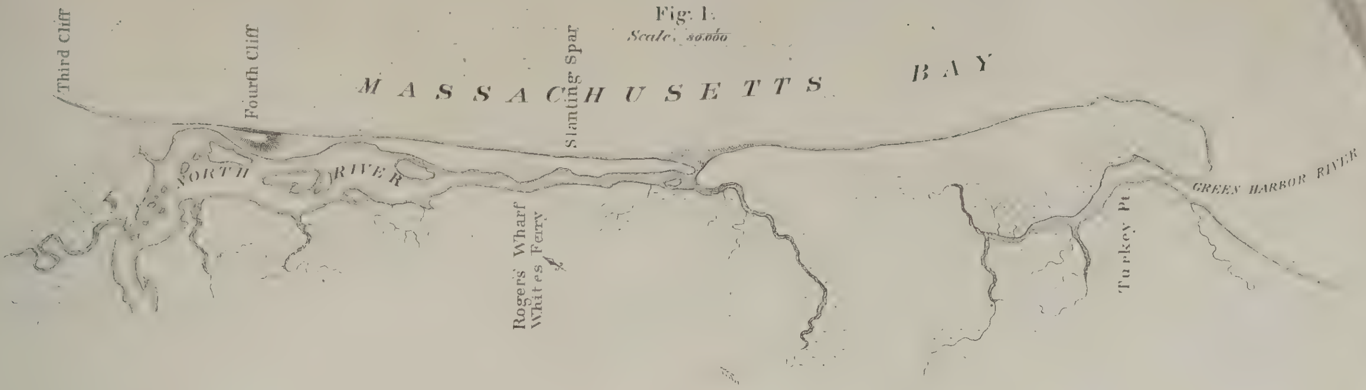


Fig: 2.

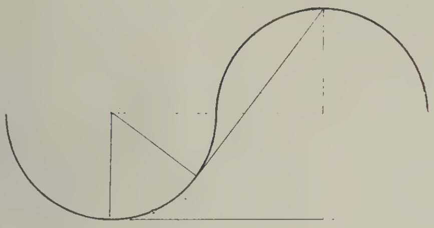
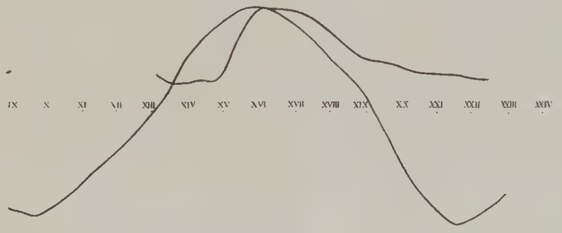
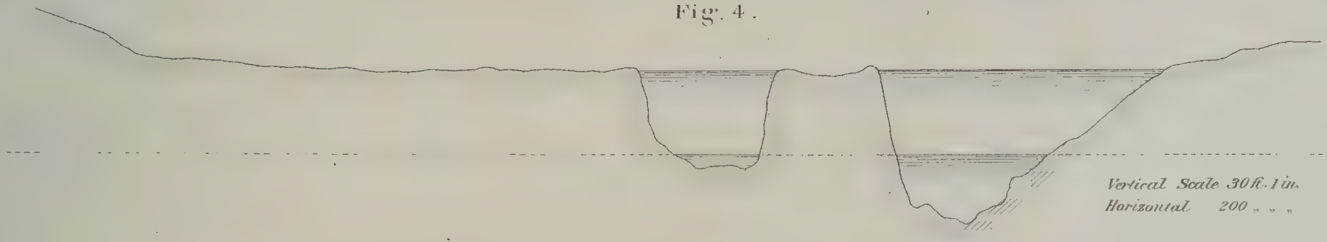


Fig: 3.



SECTION CROSSING GREEN RIVER AT TURKEY POINT, MASS.

Fig. 4.



Vertical Scale 30 ft. 1 in.
Horizontal 200 " "

SECTIONS OF SHINGLE LEVEE BETWEEN THIRD AND FOURTH CLIFFS.

Fig: 5.

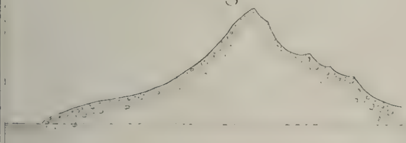


Fig: 6

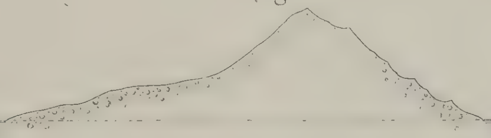
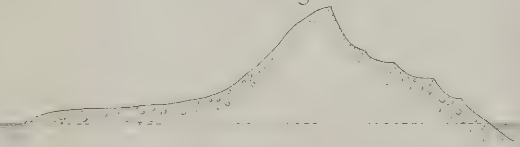


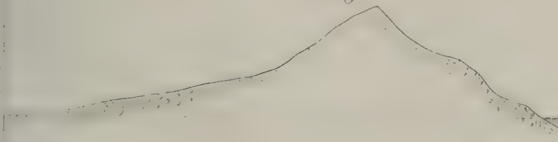
Fig: 7.



Sections 5.6.7.8. *Vertical Scale 30 ft. 1 in.*
Horizontal " 100 " "

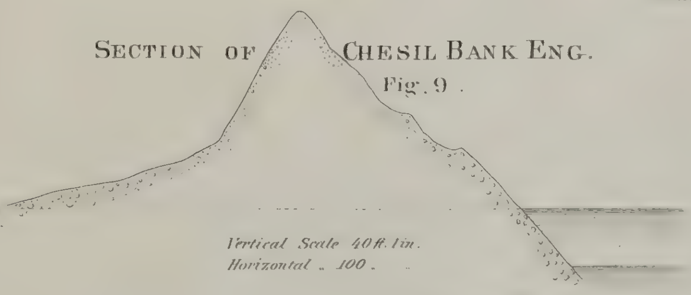
MEAN OF SECTIONS.

Fig: 8.



SECTION OF CHESIL BANK ENG.

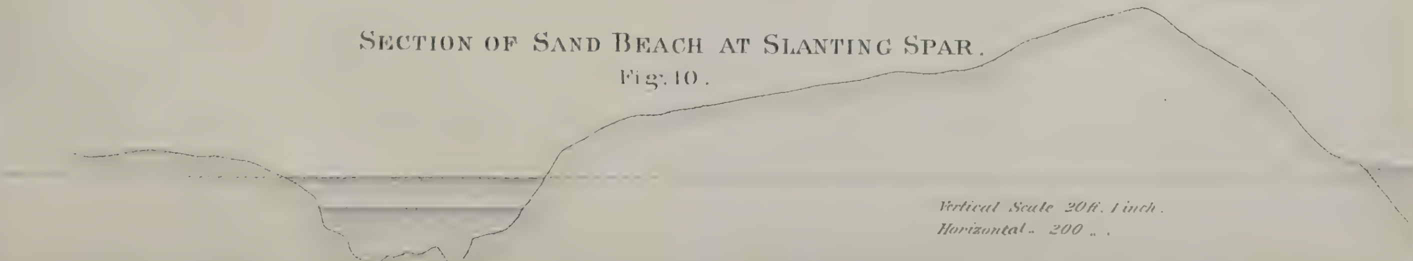
Fig: 9.



Vertical Scale 40 ft. 1 in.
Horizontal " 100 .

SECTION OF SAND BEACH AT SLANTING SPAR.

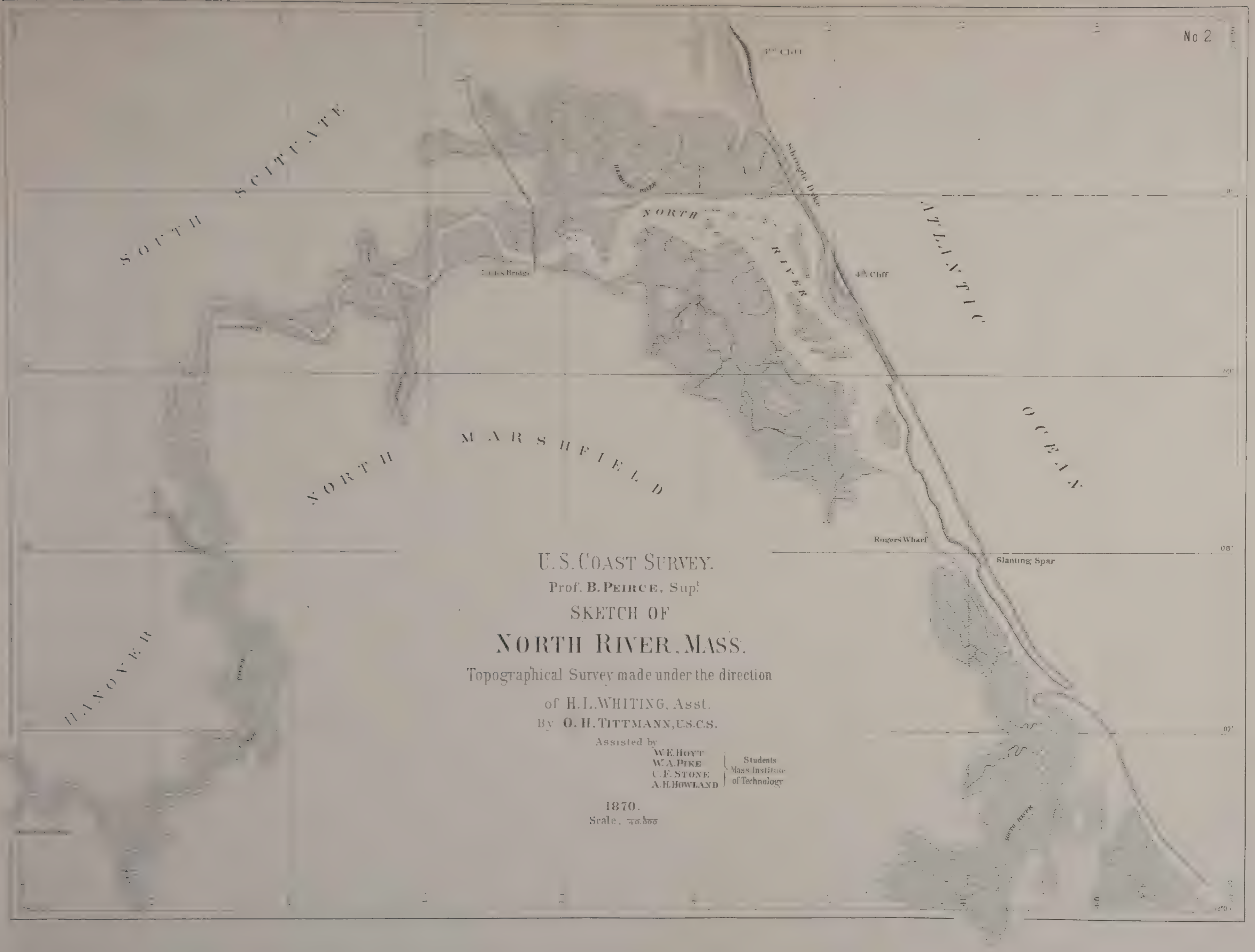
Fig: 10.



Vertical Scale 20 ft. 1 inch.
Horizontal " 200 " "

To accompany report of H. Mitchell on the Reclamation of Tide Lands.

No 2



U.S. COAST SURVEY.
Prof. **B. PEIRCE**, Supt.

SKETCH OF

NORTH RIVER, MASS.

Topographical Survey made under the direction
of H. L. WHITING, Asst.
By **O. H. TITTMANN**, U.S.C.S.
Assisted by
W. E. HOYT
W. A. PIKE
C. F. STONE
A. H. HOWLAND
Students Mass Institute of Technology

1870.
Scale, $\frac{1}{40.000}$

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